

Development and Evaluation of An Ergonomically Sound Air Traffic Control Workstation

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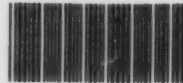
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The Arnott Design Group, Inc.

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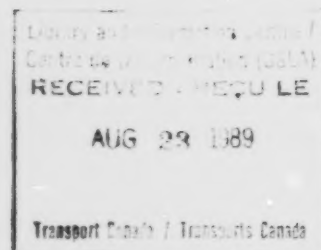
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Development and Evaluation of An Ergonomically Sound Air Traffic Control Workstation

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June 30, 1988



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Un sommaire en français de ce rapport est inclus avant la Table des matieres.

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17. Abstract This report describes the development and evaluation of an experimental workstation for Canadian air traffic controllers intended for implementation in 1993. In addition to designing and building an ergonomically suitable console, the contractor was responsible for the graphic design of the displays and the specification and implementation of the user interface software. The project began with a period of research and analysis followed by conceptual design, mockup building, prototyping, computer modelling, and culminated in the construction of a functional prototype. The prototype was evaluated in a high fidelity air traffic simulation exercise conducted by a human factors specialist. The results indicated that controllers could move rapidly into an electronic environment provided that the display systems capitalize on the potential of the processing power of the automated system.			
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SUMMARY

Introduction

Canada is in the midst of a program which will result in a complete modernization and integration of its air traffic control (ATC) systems. The Canadian Airspace Systems Plan (CASP) outlines a strategy for updating the ATC system to respond to needs up to the year 2000. In particular, it calls for increased use of automation and the replacement of obsolete equipment in order to maintain a high level of safety while improving controller productivity and minimizing costs. CASP recognizes that human factors studies will be essential to achieve these objectives.

This report describes the development and evaluation of an experimental prototype workstation for Canadian air traffic controllers intended for implementation in 1993. In addition to designing and building the console, the contractor was responsible for the graphic design of the displays and the specification and implementation of the user interface software.

The objective of this project was to provide an ergonomically sound prototype workstation which incorporates the most recent developments in interactive graphic display technology and user interface design. This prototype is intended to be used as a research tool to evaluate innovative concepts for information display and control and to provide valuable insights and information which can be incorporated into hardware and software design specifications for future ATC workstations. It is expected that these insights will lead to the development of workstations which are, in spite of their increased functionality, easier to understand and use and provide greater satisfaction to the user.

The prototype workstation, as delivered, was not intended to represent a final solution to the problem of providing electronic flight data. Rather, it should be considered as a major first step in an iterative process aimed at achieving that goal.

Summary

Method

The project began with a research and analysis phase involving numerous site visits to ATC centres; consultation with experts in the fields of human factors research, user interface design, interactive computer graphics and avionics administration and research; and a review of appropriate literature. This was followed by a period of conceptual design which involved the generation of marker renderings and construction of cardboard mockups and computer models for evaluation by controllers and Air Traffic Services (ATS) personnel. As the design progressed, interactive graphic concepts were designed, implemented and tested. Finally, an operating prototype was built and installed in the ATS Research and Experimentation Centre in Hull, Quebec. The prototype was interfaced with a simulation computer which enables on-line simulation of various Canadian airspaces.

Prototype Description

The prototype was implemented using two Silicon Graphics IRIS workstations on an ethernet network with two 19-inch, 1024 x 768 resolution, full colour raster displays. Two optical mice were used as primary input devices. The console consisted of a long, reinforced table section of fixed height bridging a pair of pedestals. Secondary controls and speakers were mounted in a wrap-around control panel. The prototype software was written in the "C" programming language and incorporated a number of innovative features which included the following:

- A menu-driven user interface for the display of operational information.
- A simulated, elevation (side) view of planned flight information.
- A transparent display mode which allows the overlaying of operational information on top of the radar display without obstructing vital radar information.
- The ability to edit numeric flight data fields using only the mouse.



- The implementation of a virtual radio control panel, i.e. the radio controls are implemented in software and user interaction takes place through the use of interactive computer graphics.

The prototype was evaluated in a series of experiments conducted by a human factors specialist. Twelve operational controllers and eighteen non-operational controllers participated in the experiments. The controllers were required to work at the prototype console in a simulated control situation. Three experimental conditions were investigated: heavy

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traffic load using radar control, light traffic load using radar control, and light traffic load using procedural (non-radar) control. In the heavy traffic condition, two controllers worked as a team, with one of the controllers operating the radar position and the other the flight data position. In both of the light traffic conditions, the workstation was operated by a single controller.

Prior to the simulation sessions, the controllers were asked to fill out questionnaires regarding the importance of various ATC activities and their satisfaction with the existing JETS workstation. Since it was not possible to provide a side-by-side comparison of the two systems, controllers were required to provide satisfaction ratings of the JETS workstation from memory. After the session, controllers filled out a similar questionnaire to determine their satisfaction with the prototype workstation.

Results

When comparing the radar position of the prototype with the existing JETS workstation, the response of the controllers did not indicate a clear preference for either workstation. The controllers were satisfied with the way a menu-driven user interface was used in the prototype to simplify access to radar display features and the OIDS data. Although controllers were satisfied with their ability to access flight progress information while working at the radar position, they were less satisfied with their ability to resolve conflicts.

When comparing the flight data position of the prototype with the existing JETS workstation, the controllers preferred the JETS workstation. However, again the controllers were satisfied with the way the menu-driven user interface was used in the prototype to simplify access to the VIPS information. The preference for JETS could be partly attributed to three factors: (1) the inability of the prototype to display flight data posted under two different fix points concurrently, (2) the lack of flexibility and ease of use in the prototype user interface for editing flight data and (3) the greater familiarity of the controllers with JETS.

Controllers commented that, although they felt comfortable using the prototype while operating the radar position, they felt unable to control effectively at the flight data position, particularly when operating in a procedural (non-radar) control environment.

Conclusions

An ergonomically sound, prototype ATC workstation incorporating the most recent advancements in computer graphics and interactive graphic interfaces was successfully implemented and evaluated, with favourable results, by operational air traffic controllers. The evaluation enabled the designers and controllers to answer many questions and, more importantly, to identify a large number of issues for further study.

The evaluation trials of the ATC workstation clearly indicated that operational controllers could move rapidly into an electronic environment provided that the displays capitalize on the processing power of the automated system. In the course of their limited exposure to the prototype during the simulations, the controllers readily adapted to the interactive graphic displays and menu-driven user interface and responded enthusiastically to the way menus were used to improve access to operational information.

Because it is difficult to improve on the ease with which data can be scribbled on paper flight strips, little performance improvement can be expected regarding the task of manually updating flight information without resorting to voice input technology. However, it *is* expected that the automation of certain controller activities (e.g. estimate calculation, estimate passing) will result in a reduced need for manual information updates and consequently an improvement in controller productivity, as well as air traffic safety, in an electronic environment.

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Recommendations

Numerous opportunities for improvements in the ATC prototype software have been identified by the controllers and designers and should be developed in future prototypes. These include:

1. Improving the efficiency and flexibility with which the user can enter or update flight progress information.
2. The automatic detection of potential conflict situations and alerting of the controller.
3. The development of new display formats for both operational and flight progress information to reduce the required amount of window manipulation (e.g. scrolling, paging) .
4. The provision of additional visual cues (e.g. cocked strip) to enhance the controller's ability to remember pending actions and verify their completion.

It is anticipated that the development of new data formats will involve giving the user more control over the size, content and location of data display windows. It is recognized, however, that an *excessive* amount of flexibility could allow some individuals to create suboptimal display formats. It will be necessary to perform further evaluation studies with the next iteration of the prototype to determine the optimal level of flexibility.

It should also be pointed out that the user interface of future ATC workstations will be influenced by a number of recently maturing technologies. These technologies will have to be examined and their impact on the user interface must be assessed within the context of the Flight Data Modernization Project. They include the use of 20 x 20 inch raster displays, voice recognition, voice synthesis and artificial intelligence.

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Introduction

Le Canada s'est donné pour tâche de moderniser et de réorganiser de fond en comble son système de contrôle de la circulation aérienne ou ATC. Son plan de réorganisation et de gestion de l'espace aérien canadien définit une stratégie de modernisation du système ATC, à l'horizon 2000. En particulier, il prévoit une automatisation plus poussée du système et le remplacement des équipements tombés en désuétude, le tout dans le but de relever la sécurité des opérations aériennes, d'accroître la productivité du contrôle de la circulation aérienne et de réduire les coûts. Ce même plan considère essentiel de faire appel à l'ergonomie.

Ce rapport décrit les travaux de mise au point et d'évaluation d'un poste de travail ATC expérimental en vue de sa mise en service en 1993. Outre les tâches d'étudier et de construire le poste, le contractant s'est vu confier celle d'élaborer le système infographique et de réaliser, après en avoir défini les caractéristiques, le logiciel devant servir d'interface entre le système et l'utilisateur.

L'étude avait pour but de déboucher sur un prototype respectant les critères de l'ergonomie et dans lequel seraient intégrées les dernières innovations en matière d'infographie interactive et d'interface homme-machine. En plus de pouvoir servir à l'évaluation des concepts novateurs proposés, ce prototype doit pouvoir mettre en évidence les caractéristiques particulières du matériel et du logiciel informatiques susceptibles d'être reprises dans des postes de travail plus évolués qui, malgré leurs possibilités plus nombreuses, sont de compréhension et d'utilisation plus aisées et permettent à l'utilisateur de tirer une plus grande satisfaction de son travail.

Le produit livré, loin d'être considéré comme la solution idéale, est au contraire vu comme la première étape d'un long processus de tâtonnements et de tentatives.

Méthode de travail

L'étude a commencé par une phase de recherche et d'analyse qui a nécessité de nombreuses visites à divers centres ATC, la consultation d'ergonomistes chevronnés, de spécialistes en conception de logiciels d'interface, en systèmes infographiques et en avionique, ainsi que l'examen de la documentation connexe. Elle s'est poursuivie par une phase d'étude conceptuelle (croquis à l'appui), par la réalisation de maquettes en carton et par l'élaboration de modèles informatiques, le tout destiné à être éprouvé par les services de la circulation aérienne, ATS. Au fur et à mesure qu'avancait le concept, des systèmes infographiques étaient proposés et testés. Enfin, un prototype fonctionnel a été réalisé et installé au Centre de recherche et d'expérimentation des services de la circulation aérienne, à Hull (Québec). Ce prototype était connecté à un SAO (simulateur assisté par ordinateur), capable de simuler divers secteurs de l'espace aérien canadien.

Description du prototype

Le prototype comporte deux postes ATC équipés d'une visualisation IRIS de Silicon Graphics connectée à un réseau Ethernet, et deux écrans infographiques couleur à balayage ligne par ligne de 19 pouces, d'une résolution de 1024 x 768, dont l'interactivité est augmentée par deux souris optiques. Le pupitre comporte une longue table renforcée de hauteur fixe supportée par deux caissons. Les commandes secondaires et les haut-parleurs sont pris dans un panneau enveloppant. Le logiciel est écrit dans le langage évolué C et comporte les caractéristiques novatrices suivantes:

- Interface homme-machine commandée par menu.
- Vue latérale simulée du plan de vol.
- Affichage transparent permettant de superposer l'information de vol sur l'information radar sans gêner cette dernière.

- Mise à jour des zones de données de vol numériques à l'aide de la seule souris.
- Pupitre de contrôle radio à commandes virtuelles, par l'intermédiaire du logiciel et du système infographique interactif.

L'évaluation du prototype s'est faite par un ergonomiste spécialisé ainsi que par 12 contrôleurs actifs et 18 non actifs. Les contrôleurs devaient utiliser les commandes dans un contexte opérationnel simulé et restituant trois régimes d'exploitation particuliers: trafic lourd contrôlé par radar, trafic léger contrôlé par radar et trafic léger dirigé selon la méthode de contrôle aux procédures (non radar). Dans le premier régime, le poste était servi par une équipe de deux, l'un au radar et l'autre au poste données de vol. Dans les deux autres cas, un seul contrôleur était en place.

En guise de préparation aux séances de simulation, les contrôleurs avaient été invités à remplir un questionnaire permettant de connaître leur appréciation du poste de travail JETS existant, en fonction des diverses opérations de contrôle à effecteur. Devant l'impossibilité de procéder à une comparaison parallèle des deux systèmes, il avait été demandé aux contrôleurs de donner au poste JETS une cotation fondée sur leur expérience personnelle. Après chaque séance de simulation sur le nouveau poste de travail, les contrôleurs remplissaient un questionnaire analogue.

Résultats

Du point de vue du contrôle radar, aucune préférence n'a pu être nettement dégagée. Toutefois, les contrôleurs se sont déclarés satisfaits de la facilité avec laquelle il est possible d'utiliser l'interface commandée par menu pour exploiter le radar et prendre connaissance des données affichées par le système OIDS (Operational Information Display System). Ils se sont également déclarés satisfaits de l'aptitude à se tenir informés sur la progression des vols à partir du poste radar, mais pas en ce qui concerne l'aptitude à prévenir les trajectoires incompatibles.

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Du point de vue données de vol, la préférence des contrôleurs est allée au poste JETS existant; mais, là encore, ils ont aimé la facilité avec laquelle l'interface commandée par menu permet d'accéder à l'information visuelle produite par le système VIP (Visual Information Presentation). La préférence pour le poste JETS peut s'expliquer en partie par les trois raisons suivantes: (1) inaptitude du prototype à afficher en même temps les données de vol concernant deux repères différents (2) manque de souplesse et difficulté d'utilisation de l'interface pour la mise à jour des données de vol et (3) meilleure connaissance du poste JETS.

Alors que les contrôleurs radar s'étaient sentis à l'aise avec le prototype, il n'en a pas été de même pour les contrôleurs chargés des données de vol, surtout à l'égard du contrôle aux procédures (non radar).

Conclusions

L'étude a débouché sur un prototype de poste ATC respectant les critères de l'ergonomie et dans lequel peuvent être intégrées les dernières innovations en matière d'infographie et d'interface interactives. Celui-ci a été réalisé et évalué avec succès, suscitant une réaction favorable de la part des contrôleurs de la circulation aérienne. L'évaluation a apporté aux concepteurs et aux contrôleurs un certain nombre de réponses aux questions qu'ils se posaient et, plus important encore, elle a soulevé d'autres questions qui devront à leur tour être résolues.

L'évaluation a montré que les contrôleurs des services ATC peuvent s'adapter rapidement à un système de contrôle électronique, à condition que les visuels soient adaptés à la capacité de traitement du système automatisé. Malgré la courte durée de séances de simulation, les contrôleurs ont su s'adapter rapidement au système d'affichage infographique interactif et à l'interface commandée par menu, et ils ont apprécié la facilité avec laquelle celle-ci leur permet d'accéder à l'information opérationnelle.

Étant donné qu'il est beaucoup plus facile d'écrire à la main sur les fiches de progression de vol qui sont en papier, la seule manière possible de rendre plus performante la mise à jour manuelle des données de vol serait de faire appel à un système d'entrée vocale. Cependant, grâce à l'électronique et à l'automatisation de certaines opérations où les appréciations se font encore par des moyens de calcul non automatisés (exemple: calcul des trajectoires et des points d'intersection), il sera possible de relever la productivité des contrôleurs, ainsi que la sécurité du réseau.

Recommandations

Divers perfectionnements dont les prototypes à venir devraient faire l'objet ont été notés tant par les contrôleurs que par les concepteurs; ce sont:

1. plus grande souplesse et plus grande facilité dans l'entrée ou la mise à jour des données sur la progression des vols;
2. détection automatique de conflits potentiels et mise en garde du contrôleur;
3. réduction du nombre de manipulations: défilement, pagination, etc., par une meilleure représentation de l'information tant sur les opérations que sur la progression des vols;
4. création de repères visuels additionnels comme le repérage visuel des fiches en attente, afin de permettre de mieux figurer l'évolution possible d'une situation de contrôle donnée.

On prévoit que, grâce au meilleur formatage des données, l'utilisateur pourra contrôler plus efficacement les fenêtres d'affichage quant à leur dimension, leur contenu et leur emplacement, sans aller toutefois au point de conférer une souplesse *excessive* au système, ce qui risquerait d'aboutir à la création de formats infraoptimaux. Le niveau optimal de

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souplesse à conférer ne pourra être établi que par des expérimentations plus poussées sur la prochaine version de prototype.

Il doit également être noté que la mise au point de l'interface destinée aux postes de travail à venir devra tenir compte d'un certain nombre de technologies actuellement naissantes. Ces dernières devront donc être prises en considération et leur impact évalué, dans le contexte du projet de modernisation des systèmes de données sur les vols. Parmi ces technologies, on dénombre les visuels à balayage ligne par ligne 20 x 20 pouces, la reconnaissance et la synthèse de la parole et l'intelligence artificielle.

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INTRODUCTION

Background

In order to respond to rapidly increasing demands, computers are being used to augment the abilities of air traffic controllers, mainly by automating time-consuming, repetitive tasks. As the complexity of the air traffic control (ATC) system increases, it becomes more important to provide a user interface which is easy to learn, easy to use and satisfying to work with. The development of user interfaces for future ATC systems is being influenced by several factors. These include the use of direct manipulation interfaces¹ and the displacement of cursive display technology by raster technology^{2,3}.

Recent years have brought about a proliferation of highly interactive, direct manipulation interfaces in personal, business and industrial computers. Interactive graphic techniques such as pull-down menus, windowing, dragging, scrolling and sliders have been used in many commercially available applications software packages. However, as yet, these techniques have been used only sparingly (if at all) in the ATC environment.

Cursive displays have a long history of practically exclusive use for the display of radar information in ATC workstations. However, with the recent development of larger and higher resolution raster display systems, raster technology appears to be overtaking the cursive systems. The many advantages of raster displays include the following:

1. They can be used under full daylight conditions.
2. They have the ability to display shaded areas.
3. They have the ability to display a large number of colours inexpensively.

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4. The screen refresh rate is independent of amount and type of data to be displayed.

History

Canada is in the midst of a program which will result in a complete modernization and integration of its ATC systems. The Canadian Airspace Systems Plan (CASP)⁴ outlines a strategy for updating the ATC system to respond to needs up to the year 2000. In particular, it calls for increased use of automation and the replacement of obsolete equipment in order to maintain a high level of safety while improving controller productivity and minimizing costs. CASP recognizes that human factors studies will be essential to achieve these objectives.

The Flight Data Systems Modernization Project (FDMP)⁵ is just one of a number of projects underway or being formulated to implement CASP. The FDMP provides for the modernization of the equipment used to acquire, distribute and use flight data and related aeronautical data needed to provide air traffic services.

One aspect of FDMP is the upgrading of the workstations used by air traffic controllers. The workstation must integrate the radar and flight data into a mutually supporting system. The FDMP calls for the development of a prototype workstation based on specifications provided by the FDMP office. The prototype will be tested and the specification will be revised based on the results of the evaluation. Operational workstations will then be built according to the revised specification.

Objective

The objective of this project was to design, build and evaluate an ergonomically suitable prototype workstation incorporating the most recent advancements in computer graphics and interactive graphic interfaces.

One premise that was stated early in the original discussions was that a human factors evaluation of the prototype workstation would *not* include a comparison between the prototype and current equipment (i.e. the JETS workstation) in terms of controller *performance*. However, the evaluation *did* include a comparison of controller *satisfaction* with the prototype and with JETS. The prototype was intended to be used as a research vehicle that would enable the exploration of a number of key conceptual issues. These included the following:

1. Can highly interactive, direct manipulation interfaces be used to improve the ease of learning and ease of use of the highly automated ATC systems of the future?
2. What are the implications of using raster display technology (instead of the traditional cursive technology) on the design and appearance of ATC displays?
3. Can the large volumes of information required to perform the air traffic control task be successfully presented in a relatively small display area by the use of interactive graphic techniques?

The results of this research would be used to specify the characteristics of the prototype. Thus, the goal of this exercise was not to provide an exhaustively complete prototype system but rather to develop a plausible simulation environment which would allow the preliminary investigation of many conceptual issues. It was anticipated that the results of the evaluation would provide direction for subsequent prototypes which would be more complete and of higher fidelity. Thus, the prototype workstation, as delivered, is not intended to represent a final solution to the problem of providing electronic flight data. Rather, it should be considered as a major first step in an iterative process aimed at achieving that goal.

Introduction

Presently, in a typical air traffic control operation, each sector of airspace is controlled by a pair of controllers -- one controller observes the radar display and handles communications with pilots while the other manages flight data. However, during periods of relative inactivity (e.g. late at night) a single controller will operate both the radar and flight data positions. One of the requirements of the prototype was to provide a facility which would enable operation by either one or two controllers. Another criterion for development of the prototype was that the prototype had to provide the controllers with the same level of cognitive understanding that they presently enjoy using the paper flight data strips.

2 METHOD

The project was broken down into four major phases: Research and Analysis, Design and Development, Prototype Construction, and Evaluation. Because of its experimental nature, there was considerable overlap between phases throughout the project. Each of the phases is described in detail below.

Phase I: Research and Analysis

The first phase of the project involved research into the nature of the air traffic controllers' task and subsequent analysis of the information gathered during this period. A detailed list of the activities which took place is provided below.

1. A steering committee was formed with representatives from the Department of Supplies and Services (DSS), the Transportation Development Centre (TDC), Air Traffic Services (ATS) and the Research and Experimentation (R&E) centre. Throughout the entire project, progress was monitored and recommendations for further activities were provided by the steering committee.
2. The current scientific and popular literature regarding human factors and air traffic control was reviewed and summarized. This included the most recent developments from the Federal Aviation Administration (FAA) and European air traffic control environments.
3. The task of air traffic control as currently practised by controllers using the JETS console was observed at three sites selected by the steering committee: Toronto ACC, Gander ACC and Vancouver ACC. The first

Method

two sites represent radar control and oceanic control environments respectively.

4. Periodic discussions were held with air traffic controllers, members of the FDMP development team and staff from the Air Traffic Services (ATS) Research and Experimentation centre to review and criticise the current version of the workstation prototype at various points during its development.
5. A number of specific sites selected by the steering committee were visited by members of the project team. These sites included the IBM development laboratory for the FAA Advanced Automation Project,⁵ and the Eurocontrol research and development facility.
6. A design brief describing the proposed configuration of the prototype workstation and description of the simulation was prepared.

Phase II: Design and Development

The conceptual design of the workstation and its subsequent development into a realizable product involved a series of overlapping and iterative activities which are listed and described in detail below.

1. Concept renderings. Designers prepared a series of renderings to convey the conceptual aspects of design proposals. These renderings were made in both orthographic and perspective views.
2. Computer modelling. Some of the workstation concepts were modelled using Alias/1 software on the IRIS 3030 computer in order to view them from many different angles. Final drawings of the workstation were generated by transferring data to the Unicaad DD/C CAD software for plotting.

Development of an Ergonomically Sound Air Traffic Control Workstation

3. Card board mockups. Card board and gaterboard mockups of selected workstation concepts were constructed in order to evaluate the scale and kinesthetic aspects of the concepts.
4. Design drawings. Once the final configuration was selected, design drawings specifying every aspect of the design for manufacture were prepared and checked. Assembly drawings of the workstation were generated on a plotter using the Unicad DD/C CAD software.
5. Software and graphics. Throughout the project, graphic concepts were designed and prototyped using the IRIS 3030 computer and the "C" programming language. The prototypes were subsequently evaluated by the steering committee and user groups. This process allowed controllers and management to make a continuous contribution to the specification of the user interface.

Phase III: Construction

1. Console millwork. Construction of the console millwork was performed by an outside vendor according to detailed mechanical drawings provided by the contractor.
2. Software implementation. Implementation of the prototype software was performed by an outside vendor in accordance with detailed, written specifications provided by the contractor.
3. Hardware implementation. The design and construction of the electronic hardware was performed by an outside vendor according to specifications provided by the contractor.
4. Installation and testing. The various components of the prototype workstation were assembled and integrated by the contractor with assistance from the software and electronics hardware vendors. The completed workstation was interfaced with the simulation computer

Method

and communications systems at the Research and Experimentation Centre in Hull with the assistance of R&E technicians.

Phase IV: Evaluation

An evaluation of the ATC workstation prototype was conducted by Dr. Paul Stager, a human factors specialist and professor at York University. Dr. Stager has extensive experience in the measurement and analysis of the behaviour of air traffic controllers. The method and procedures employed during the formal evaluation are described in detail in the Evaluation section (4) of this report.

In addition to the formal evaluation, a representative of the Arnott Design Group was present during the sessions to make informal observations and to record the controllers' comments. These observations and comments are provided in Appendix D of this report.

On the basis of the evaluation procedures, a list of recommendations were compiled and appear in the Recommendations section (6) of this report. This section also identifies areas where further work is required.

3 PROTOTYPE DESCRIPTION

Anthropometric considerations

During the design of the workstation, Henry Dreyfuss Associates' *Humanscale*⁷ series, amongst others, was used as the primary reference source for anthropometric data.

Although the existing population of air traffic controllers is predominantly male, Transport Canada is committed to the hiring of more female controllers in the future and expects the proportion of females to approach 50 percent. Therefore, the specification of the console dimensions is based on providing an optimal working environment for both male and female users.

Work surface height

Ideally, a desk or work surface should be adjustable in height from 635 mm to 762 mm. However, because there are typically two people working at an ATC console this is not a practical solution. If the two users are different in stature, then the table height can be optimally adjusted only for one of them. A dual level table would provide independent adjustability but, because of the close physical interaction which is typical of air traffic controllers, the resulting discontinuity of the table would be extremely annoying for both users.

For this reason, it was decided that a fixed table height should be used. Historically, 762 -787 mm has been used as a standard desk height. However, this height accommodates only average-to-taller males. Most women are left with the choice of sitting high with feet dangling or sitting low with elbows raised too high and with a reduced normal reading distance.

Prototype Description

A fixed compromise height of 711 mm is recommended by Diffrient et al.⁷ This height accommodates the greatest part of the adult population with only the very small woman experiencing difficulties.

Knee clearance

The minimum space required under the console to accommodate the knees and feet is as follows: 635 mm vertical, 380 mm horizontal directly under the work surface and 600 mm horizontal at the floor level. The prototype console (see Figure 1) provides 660 mm vertical and 590 mm horizontal directly under the work surface. Since the console is open at the floor level, horizontal clearance is limited only by placing the console against a wall which would limit horizontal clearance to 1032 mm.

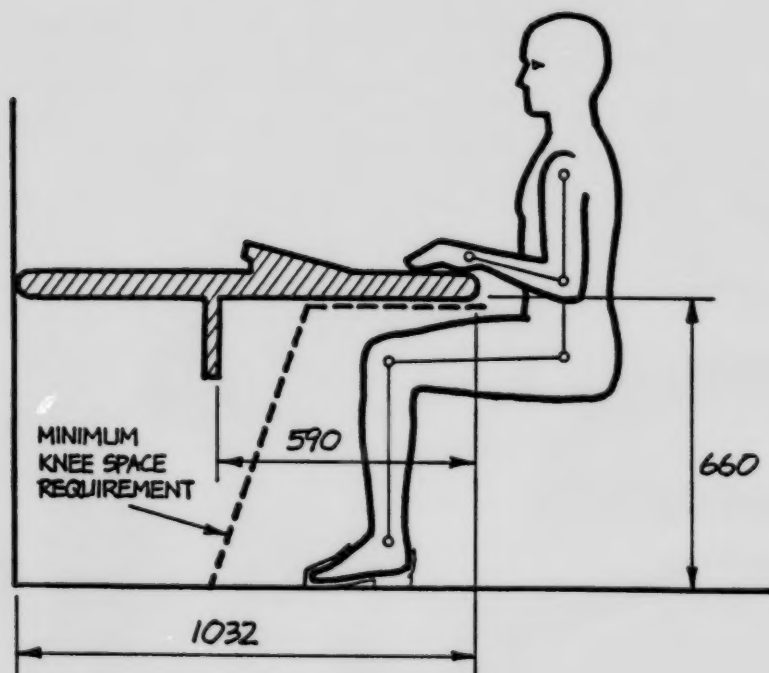


Figure 1: Knee clearance.

Monitor height

Ideally, the surface supporting the monitor should be adjustable in height from 620 mm to 890 mm. However, for the reasons discussed above, a fixed monitor support height was specified. According to Lueder⁹, 10-15° below the horizontal is generally held to be a comfortable viewing angle. Diffrient et al⁷ hold that critical displays should be located within plus or minus 15° of the normal sight line. Therefore, critical displays should be located within a viewing angle range from 5° above the horizontal to 30° below. Discomfort results when the viewing angle exceeds 40° below the horizontal.

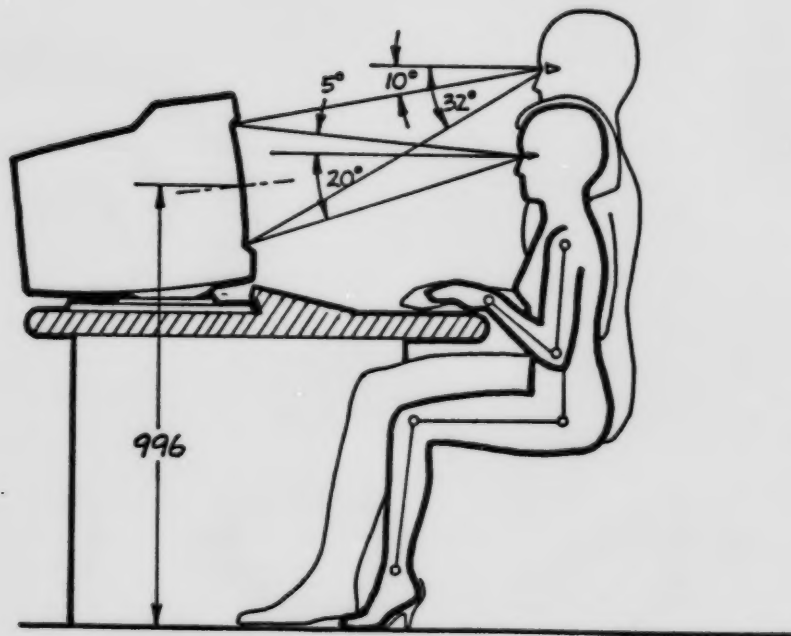


Figure 2: Monitor height

Prototype Description

A fixed support height of 711mm places the screen centre of the monitor at 996 mm from the floor. When looking at the bottom edge of the screen at this height, the viewing angle for a large man seated at the prototype is 32° below the horizontal. When looking at the top edge of the screen, the viewing angle for a small woman is 5° above the horizontal. These relationships are illustrated in Figure 2. Although the viewing angle for the large man exceeds the range described above, the deviation is relatively small and therefore it is felt that the 711 mm support height represents a reasonable compromise.

Monitor angle

Most high quality monitors are manufactured with an integral tilt/swivel mechanism. A tilt range of plus or minus 20° is considered to be ideal⁸ while plus or minus 7° is a minimum acceptable range. The monitors which are currently supplied with new Silicon Graphics IRIS workstations have a tilt range of plus or minus 10° which fulfills the minimum requirement.

Aside from problems with glare, the screen surface should ideally be oriented perpendicular to the sight line. Viewing angles of up to 30° from the perpendicular are acceptable. However, when viewing angles exceed 45° , the legibility of the display is degraded. The maximum viewing angle of 22° is experienced by the large man using the console with the monitor tilted back 10° . This is well within the acceptable limit.

Control panels

Panel orientation

Although control panels are traditionally oriented at a high angle (30° to 85°) relative to the horizontal, the control panels in the prototype were set at 15° in order to bring them in line with the keyboard. Recommended keyboard angles are $11-15^{\circ}$. The relatively shallow angle makes it slightly more difficult to position all of the controls within reach. However, for all but the smallest female, all of the controls are within reach of the operator, with the exception of the telephone handset.

Seating

All of the design criteria described above depend on the provision of proper seating. Kinetics model 105/903 business seating was selected for this application. Seat height is adjustable by the user through a range of 381 to 559 mm which covers almost all of the 380 - 570 range recommended by Leuder⁸. Seat pan angle is adjustable by the user between 5° backward and 4° forward. The front edge of the seat pan is softly padded with a radius of about 25 mm. Backrest angle is adjustable by the user between 20° backward and 15° forward (optional). The armrests are short to permit a close approach to the work surface. If necessary, the armrests are easily removable. The five-caster base, a European standard, reduces the potential for tipping. A long, sloping (15 degrees) footrest should be provided for short users.

Hotline panel

Hotline controls

There are 16 hotline channels provided in a panel 356 mm wide by 241 mm deep. (See Figure 3.) They are arranged in 4 modules, each providing 4 channels. Each channel is controlled by five push button switches: on/off, headset/speaker, volume up, volume down, and push-to-talk. The function of each of these switches is described in Table 1.

The volume levels are adjusted by using push button controls. The interaction is similar to that of remote control devices used with domestic television. Two volume control buttons, labelled "+" and "-", allow the controller to increase or decrease the volume level by an incremental amount. While volume is being adjusted, the volume level is graphically displayed in the LCD display. This interaction is described in more detail in Appendix E.

Prototype Description

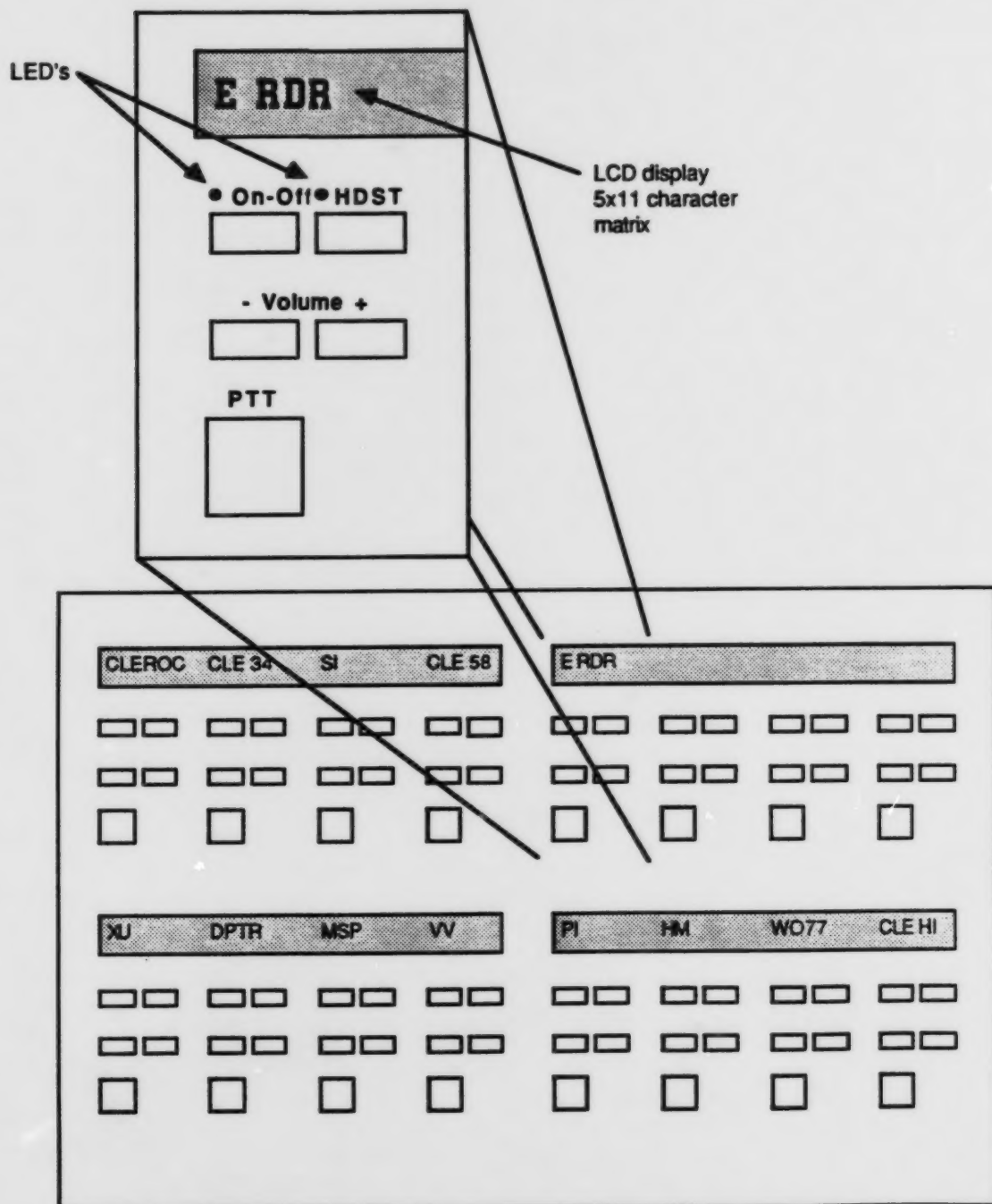


Figure 3: Hotline Panel

Table 1: Hotline control switch characteristics.

Switch Name	Switch Action	Remarks
On/Off	ON/OFF	LED lit when off
HDST	ON/OFF	LED lit when HDST on
Volume [+]	momentary	
Volume [-]	momentary	
PTT	momentary	Illuminated keycap flashes during incoming message.

Hotline display

The hotline panel uses four 40-character LCD display devices to identify the hotline channels. Each hotline channel uses 10 of the 40 characters in the display. Unlike the JETS console, the hotline identifiers are displayed horizontally rather than vertically since vertically written words are difficult to read. Backlit LCD's were specified for the prototype console. However, it was not possible to obtain the required components without compromising the delivery schedule of the prototype. Although conventional LCD's were used in the prototype console as a result, it is recognized that they can be difficult to read in low light conditions and that backlit LCD's are preferred for this application.

User interface

Cursor positioning device

An optical mouse (model M2 manufactured by Mouse Systems Corp., Santa Clara, CA) was used as a cursor positioning device for the prototype workstation. A special pad is required to operate the mouse. The pad is made of a rectangular (19.7 x 22.8 cm) piece of specular aluminum which has been etched using a proprietary process. Four thin neoprene feet, 2.5 x 2.5 cm, are glued to the underside of the pad to help prevent the pad from sliding on the table. The gain of the mouse movement to cursor movement is sufficiently high to enable the user to move the cursor to all four corners of the screen without lifting the mouse from the pad.

Optical vs. mechanical mice

The mouse has been proven to be an extremely compatible device for cursor positioning tasks⁵. There are two types of mice in common use: mechanical and optical. The mechanical mouse contains a ball which rolls as the mouse is moved across the work surface, turning a pair of encoded shafts within the mouse. The optical mouse contains an infrared emitter which produces a beam which is reflected off a special surface and is read by a photo-detector also contained in the mouse.

The main drawback of optical mice is the need for a special surface, generally provided in the form of a small pad, to operate the mouse. The pad causes irritation by constraining the movement of the mouse. Optical mice are also sensitive to orientation with the mouse pad and can behave unpredictably if the angle between the mouse and pad deviates from the "normal" orientation by more than plus or minus 45 degrees. Although neoprene mouse pads are sometimes used with mechanical mice to enhance performance, their use is not mandatory. Mechanical mouse pads are not sensitive to orientation.

Precision

In general, optical mice have less friction and mechanical inertia than mechanical mice. This characteristic makes the optical mouse more suitable for precise work. However, the performance of mechanical mice can be improved through the use of computer algorithms which dynamically alter the gain of the mouse according to the speed of mouse

movement. When the mouse is moved quickly, the gain is increased so that a small but quick mouse movement produces a large cursor movement. When the mouse is moved slowly, the gain is decreased, making precise work easier.

Reliability

In principle, an optical mouse should be more reliable than a mechanical mouse because it has no moving parts. Also, it is more difficult for dust and debris to enter the mouse body. The ball in the mechanical mouse has a tendency to pick up dust and soil from the work surface and transfer it into the mouse. As a result, it is necessary to clean mechanical mice from time to time to avoid a gradual degradation of performance (e.g. sticking). But while the optical mouse itself may be more reliable than the mechanical mouse, the special *surface* required for the optical mouse is susceptible to damage or degradation from scratches or soil.

Data editing

One of the innovative features of the ATC workstation is the ability to edit numeric flight progress information using only the mouse. This innovation is intended to minimize the amount of keyboard activity required by the controller.

For example, if the controller wishes to clear an aircraft to a new altitude, he uses the cursor to point at the aircraft's current altitude, presses and holds the left mouse button while moving the mouse. If the mouse is moved away from the user (so that the cursor moves up on the screen), the number displayed in the altitude field increases in value. If the mouse is moved towards the user (the cursor moves down), the number decreases in value. When the value displayed in the altitude field matches the desired value, the controller releases the mouse button. A second button press is required to confirm the new altitude. This interaction is described in greater detail in Appendix E.

Information display

Directional aircraft icons

In the prototype radar display (see Appendix F, plate B), an arrowhead shaped symbol is used to represent the location of aircraft. The orientation of the symbol coincides with the heading of the aircraft. This symbol shape was selected on the basis of the experience of the contractor and was accepted for use by the steering committee and members of the users group.

Elevation display

In the radar display (see Appendix F, plate B), both the horizontal and vertical directions represent distance (range). The altitude of the aircraft is inferred from the information contained in the corresponding data block. In the elevation display, the horizontal direction represents time while the vertical direction represents altitude. The aircraft's position in the plan view must be inferred from the route and speed information contained in the flight progress strip.

The elevation display – part of the flight data display (see Appendix F, plate C) – is a first attempt to provide a graphic representation of flight progress information. Unlike the radar display, which indicates the *actual* positions of aircraft, the elevation display indicates their *planned* positions. The elevation display also differs from the radar display in the perceived point of view. While the radar display presents a plan view (top view) of the traffic situation, the elevation display presents a side view (elevation).

Flight data format

Aircraft identifiers

In the JETS flight data strip, the aircraft identification information is printed at either end of the strip, on the left if the aircraft is westbound, on the right if eastbound. In the prototype, the identification information is displayed in the middle of the "strip". This consistently central placement makes it easier for the controller to scan a stack of strips since all the identification information lines up in a column.

Route information

In the JETS flight data strip, the various points comprising the aircraft route are displayed on a single horizontal line of text. In the prototype, the route is displayed in a vertical format. There are several advantages to a vertical format. (1) Less eye movement is required to scan vertically formatted route. (2) The vertical format is more compact and therefore allows the display of more strips.

Although as many as 16 points can be stored for each route, the route window is only large enough to display four points at a time. However, the controller can view the entire route by using a "scrolling" feature. This feature is described in Appendix E.

Eastbound/Westbound indicator

In the JETS flight data strip, the general heading of the aircraft is indicated by the location of the identification information, as mentioned above. Since identification information is always displayed in the same location in the prototype, it was necessary to provide some other way of indicating general headings. This was accomplished by using large triangle-shaped pointers at either end of the strip.

Flight strip sequencing

Controllers presently manually sort flight strips by fix point and then arrange them in order of fix time. In the current version of the prototype software, sorting and arranging of flight strips is done automatically. If the fix point or fix time of a flight strip are edited, then the flight strips are automatically sorted and arranged again.

Transparency

The user can display an OIDS information window "on top" of the radar display. In earlier versions of the prototype software, this would temporarily obscure the radar information. However, a special technique was developed in which the OIDS information screens appear to be semi-transparent, thus allowing the "underlying" information to "show through".

This effect was achieved through the use of writemasks¹⁰ and the careful specification of the colour map. Writemasks allow images to be layered by

Prototype Description

by preserving the contents of specific bitplanes from subsequent write operations. If colours in the colour map are specified correctly, the illusion of transparency can be achieved.

Environmental Issues

Lighting

Illumination level

Although it is anticipated that the use of documents in the ATC environment will decrease, it seems unlikely that they will disappear entirely. When working with VDT displays, a low light level is desired in order to maintain the legibility of the display. However, higher light levels are required when working with hardcopy documents. A compromise ambient illuminance level of 300-500 Lux provides sufficient light for working with documents without seriously reducing the contrast of the VDT.¹⁰ Because older people (i.e. 40 years and older) may require more light than the young, it is also necessary to provide an additional 500-800 Lux of localized task lighting which can be controlled by the user.

Lighting installation

All luminaires should be equipped with either parabolic or straight louvres or baffles to reduce horizontal dispersion of light and prevent glare. If fluorescent fixtures are used, the tubes should be oriented parallel to the viewing direction of the operator. Luminaires should also be located to either side of the screen rather than being positioned in front of or behind the screen. (See figure 4.)

Reflectances and finishes of principal surfaces

High reflectances are recommended in order to avoid a dreary environment. The recommended values are shown in Table 2. The use of high surface reflectances increases the amount of diffuse light in an environment and thus reduces the prominence of light sources in the room. However, glossy surfaces should be avoided. Matte surfaces are recommended.

Development of an Ergonomically Sound Air Traffic Control Workstation

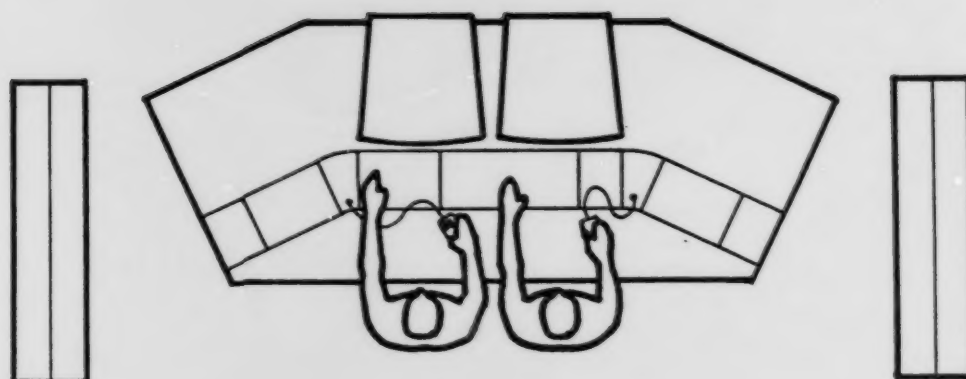


Figure 4: Recommended position and orientation of luminaires.

Table 2: Recommended reflectances of principal surfaces in a space containing VDT's.

Surface	Recommended Reflectance
Ceiling	0.7 or more
Walls	0.5 - 0.7
Floor	0.3
Immediate surround to VDT	0.2 - 0.5

Prototype Description

Acoustics

Privacy

Before complete recommendations can be made regarding the acoustic characteristics of air traffic control rooms, a number of policy decisions must be made. Presently, hotline and radio conversations between controllers and pilots or other controllers are tape recorded. On the other hand, direct conversations between controllers at adjacent workstations in a control room are not recorded. If it is felt that all voice communications between controllers should be recorded, then one way of ensuring this is to make direct conversation impossible by placing acoustic screens in between workstations. This would force controllers to use the hotlines to communicate with other controllers in the same room. On the other hand, if direct conversation is considered a useful communication channel which should not be abandoned, then acoustic screens should not be used. It is obvious that privacy requirements must be determined before acoustic recommendations can be made.

It is anticipated that acoustic requirements will also be significantly affected by the future implementation of voice input technology.

4 HUMAN FACTORS EVALUATION

The Air Traffic Control Workstation (ATCWS) was designed as a vehicle for exploring the application of an advanced interactive graphics capability to air traffic control. In order to determine whether possible design concepts would meet the requirements of controllers, the prototype workstation was assessed in terms of (a) the ease with which the operations associated with the new workstation could be mastered, (b) the ease of use once the system was mastered, and (c) the satisfaction that the operators had with the system during a significant operating trial period. The assessment was based on controller ratings of the ATCWS and the JETS system that is currently operated in the area control centres and on discussion with the controllers during debriefing sessions that followed a sequence of simulation exercises.

Method

Subjects

Twelve operational controllers (two controllers from each of the six administrative regions) participated in the formal evaluation trials. They ranged in experience in both radar and non-radar control from 5 - 32 years with an average of 17.3 years.

Simulation Exercises

The simulation exercises were based on two parallel half-hour blocks of traffic from the Centralia sector in the Toronto Flight Information Region (FIR). The volume of traffic increased in a ramp function over time. The first scenario represented a moderately heavy volume of traffic for the Centralia sector at about 2100 hr local time. The second scenario

represented a lighter traffic load and was intended for the single controller situation. In addition to the simulated radar environments, the evaluation included a non-radar scenario based on the light-load block of traffic. The traffic loads represented in each of the scenarios and the mean levels of communications activity in the two scenarios under radar and non-radar conditions are shown in Figures 1-3 in *Appendix A*. In the absence of any comparison information, statistical analyses were not planned for the communications data. The communication and traffic load information was collected only to provide a relative indication of controller workload in each scenario.

The impact of combining two sectors at one workstation on the controller's performance and on their assessment of the ATCWS was not examined in the current evaluation study in view of the limited simulation time available.

Questionnaires

A useful method for comparing two alternative workstation designs is to determine what the users perceive to be the most important features or component tasks at the workstation and then to determine how satisfied they are with those same features. A satisfaction rating is obtained for both workstation designs by having the users rate their satisfaction with features that are common to both workstations.

In the present study, the controllers completed a questionnaire in order to determine the level of *importance* that they would assign to several components of their work and their working environment. They also rated their level of *satisfaction* with those same components in the current JETS system and in the prototype ATCWS. The ratings were made on a scale of 1 (*Not At All Important/Satisfied*) to 5 (*Extremely Important/ Satisfied*). A copy of the three-part questionnaire is shown in *Appendix C*.

Procedure

Two controllers representing a given region participated in an eight-hour evening evaluation session at the Air Traffic Services Research and Evaluation Centre in Hull. Formal sessions for six pairs of controllers were completed over a two-week period.

Prior to beginning the evaluation trials, the controllers were briefed on the scheduled scenarios and the purpose of the evaluation. (Refer to the Introduction, *Appendix C*). The controllers then completed the *Importance* questionnaire and the *JETS Satisfaction* questionnaire. The controllers received a briefing on the features of the graphics displayed at the radar and data positions of the workstation and on the procedures for the Centralia sector. They were then provided with an opportunity to familiarize themselves with the capabilities of the interactive displays.

Each evaluation session comprised six half-hour traffic segments. The heavy-load scenario was run first. Each controller worked either the radar or data position for the first half-hour and then changed positions with the second controller when the scenario was repeated. Each controller then worked for one half-hour with the radar and data positions combined in the light-load scenario. Finally, each controller completed a non-radar scenario based on the light-load block of traffic. At the conclusion of the simulations, the controllers completed the *Satisfaction* questionnaire for the ATCWS and discussed their observations during the debriefing. The controllers were also encouraged to provide verbal comments during the simulations.

Results

Questionnaire Data

The ratings obtained in the questionnaires for the 12 operational controllers were averaged across subjects and the mean values were incorporated in a series of cross tabulations of importance versus satisfaction. In the following figures, quadrants were generated by locating the vertical and horizontal axes at the mid-points of the rating scales (i.e., *moderately satisfied* and *moderately important*). Ideally, items rated as being more important should cluster in the upper right quadrant. Data points in the upper right quadrant represent task components which were rated as at least moderately important and also moderately satisfactory or better by the controller. Data points in the upper left

quadrant refer to components that were rated as important but unsatisfactory. Figures 5 and 6 are intended to illustrate *only the general trends* that were observed in the controllers' ratings. The individual components are identified in Figures 7 and 8.

Figure 5 presents a comparison between the ratings for the current JETS system and the prototype workstation in terms of the radar position. There was not a clear preference for the radar position in either the JETS workstation or the ATCWS: As shown in Figure 5, the clusters of components associated with each workstation are not distinctly separated although the ratings of the JETS items showed less dispersion to either side of the neutral point than those for the prototype. As shown in Figure 6, the controllers appeared to be generally less satisfied with the data position of the ATCWS than that of JETS: The ATCWS components are clustered in the upper left quadrant (i.e. they were rated as being relatively high in importance but low in terms of satisfaction).

The ratings obtained for specific components of the ATCWS and JETS radar positions are identified in Figure 7. The controllers approved of the ease with which the radar plan display in the ATCWS could be modified (ability to select IM features [9] and ease of feature selection [10]), and the rapid access to the OIDS display (ease of OIDS selection [15]). In contrast, the ability to track revisions in flight data (awareness of revisions [8]) was rated as being very important but relatively unsatisfactory in the ATCWS. Flight data revisions on the electronic strips involved the actual deletion and replacement of displayed information rather than the simple checking or crossing out that is done on the paper strips. The rating may also have reflected the radar controller's more limited access to information that was displayed at the data position.

A comparison of the data for the ATCWS and JETS in Figure 8 indicates that the controllers were less comfortable in working with the ATCWS data position. Conflict processing was rated as being the most important but also the most unsatisfactory component of the ATCWS data position (reviewing flight data [3] and conflict processing [4]). This result was most likely related to the fact that controllers were limited to sequential rather than concurrent access to strip bays. The discrepancy in ratings between the JETS and prototype workstations may have been related as well to the adjustment that was required in learning to work with the electronic flight data.

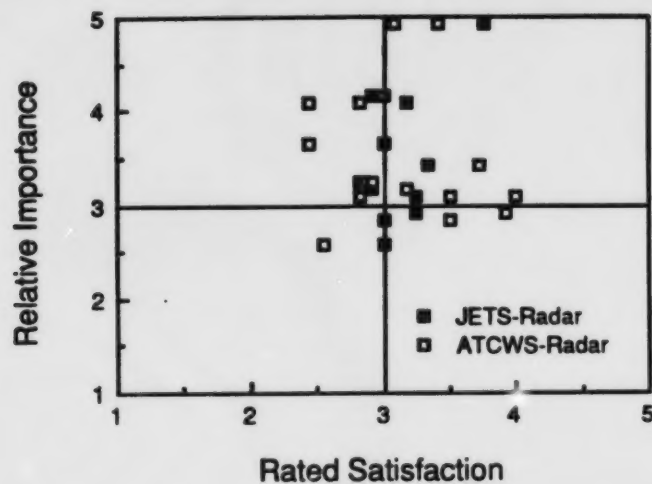
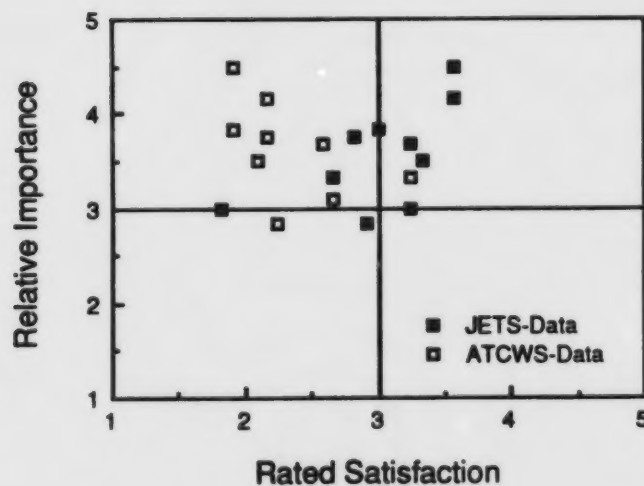
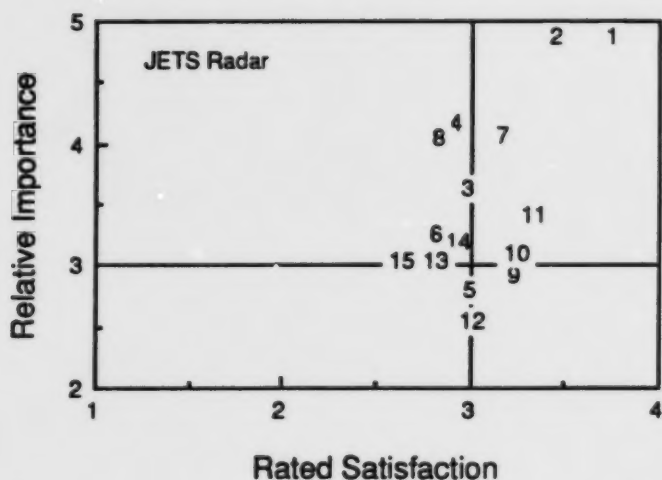
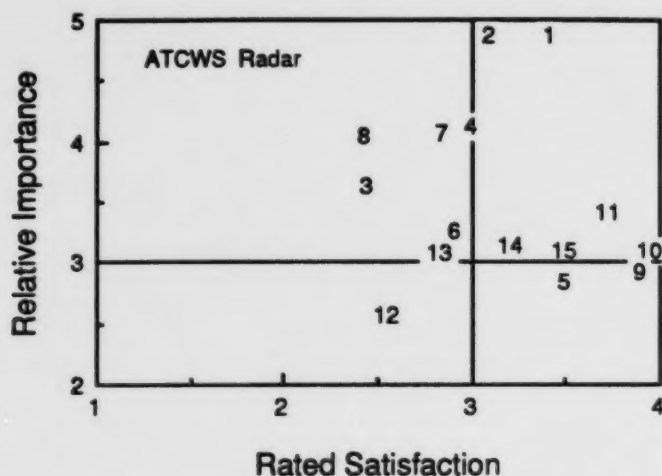


Figure 5: Rated satisfaction versus the Importance that was assigned to characteristics of the radar positions for JETS and the ATCWS.

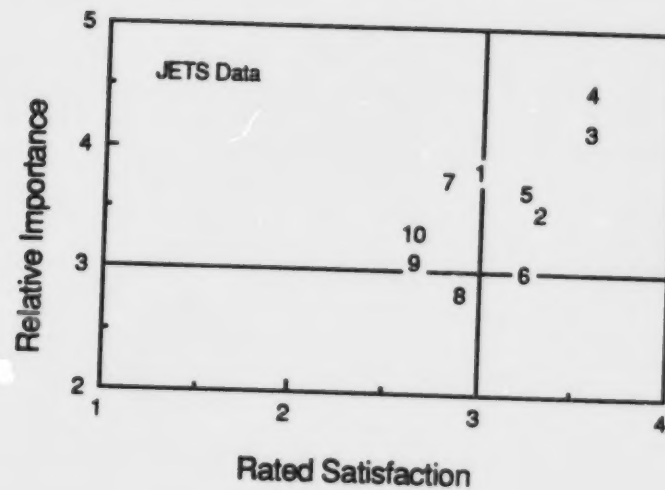
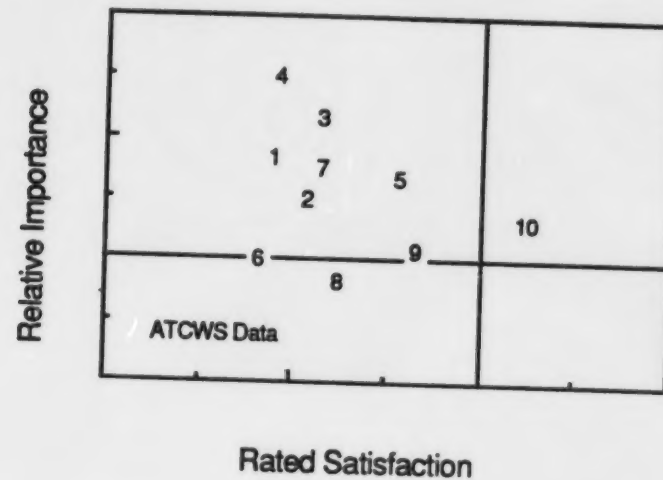




- | | | |
|---------------------------|----------------------------------|-----------------------------|
| 1. Checking separation | 6. Access to flight progress | 11. IM display refresh rate |
| 2. Resolving conflicts | 7. Revision of flight data | 12. Housekeeping activities |
| 3. Processing deviations | 8. Awareness of revisions | 13. Status information |
| 4. Reviewing flight data | 9. Ability to select IM features | 14. OIDS display |
| 5. Access to flight plans | 10. Ease of feature selection | 15. Ease of OIDS selection |

Figure 7. Satisfaction versus Importance ratings for components associated with the radar position for the ATCWS (upper plot) and JETS (lower plot). (For JETS, the coordinates for items 13 and 15 are the same.)

Development of an Ergonomically Sound Air Traffic Control Workstation



- | | | |
|---------------------------|-----------------------------|-----------------------|
| 1. Processing time info | 5. Updating flight progress | 9. Status information |
| 2. Flight plan amendments | 6. History of changes | 10. VIPS displays |
| 3. Reviewing flight data | 7. Access to board | |
| 4. Conflict processing | 8. Housekeeping activities | |

Figure 8: Satisfaction versus importance ratings for individual components associated with the data position in the prototype ATCWS (upper plot) and in JETS (lower plot).

(In addition to the 12 operational controllers, 18 non-operational controllers and engineers within Air Traffic Services participated informally in supplementary evaluation trials. Questionnaire data for these non-operational personnel are reported in *Appendix B*.)

Controllers' Comments

The comments that were received from the operational controllers during the simulations and on the questionnaires were consistent with the results that have been presented for the importance and satisfaction ratings. The controllers reported that they felt comfortable in working with the radar presentation of the ATCWS but that they were unable to control effectively at the data position, particularly in the non-radar environment. Several recommendations for future enhancements of the workstation appeared consistently in their comments. These included the recommendation that the controllers be able to display intended tracks and predicted conflicts and that effective warning messages be available to provide information on the status of the system processor.

Radar Position. Many of the comments on the ATCWS radar position indicated that the controllers would be prepared to perform more direct functions with the flight data at the position. Positive comments referred to structure of the data blocks on the displayed flight plans, the concept of transparent overlays or windowing, and the use of the mouse to acquire information on a displayed aircraft. Controllers reported that the prototype elevation display of pilot estimates and altitude information at the data position was difficult to interpret but that they would like to be able to generate a similar display on command at the radar position for selected airways in their sector. The most consistent criticism of the radar graphics concerned the excess of steps required to complete a task such as a handoff or the revision of a flight strip.

Data Position. The controllers commented positively on the assistance that the elevation display with further refinement could provide in conflict prediction. Additional suggestions for enhancing the flight data display included the provision of a conflict alert, an action warning/pending indicator, highly salient aircraft identification and altitude information, and an altitude filter to assist in scanning the electronic "board". The controllers were concerned with the inability to scan multiple strip bays (as

well as more strips) concurrently and the fact that revising an estimate on a strip immediately altered the position of the strip in the bay. Their comments reflected a dependence on a spatial/temporal map of the board and the manual sequencing of the strips. The revision of strip information was found to require a larger number of discrete steps than would be optimal in an operational system.

Some of the more general comments indicated a preference for larger display surfaces and the allocation of *all* auxiliary information (such as weather and system status information) to the flight data display.

Conclusions

The evaluation trials of the ATCWS clearly indicated that operational controllers could move rapidly into an electronic environment provided that the displays capitalize on the processing power of the automated system. The controllers adapted readily to the interactive displays during their limited exposure to the simulations and their performance appeared to be limited only by the current software of the prototype itself.

The most effective control performance will be achieved in part through a reduction in the number of control actions that are required in routine controller interactions with the displays. Most of the suggestions for workstation enhancements were associated with the flight data position although, in the long run, the current role of the data position may be considerably modified with the introduction of a highly automated flight data system.

As a result of the developmental work represented by the current prototype workstation and its evaluation, several areas of focus for subsequent research have been identified.

1. Determining the optimal mode of interaction with the displays of the workstation given the advancement in graphics that can be expected prior to implementation.

2. Regarding implementation policy: What is the optimal balance between standardizing the kinds of displays to which controllers have access and at the same time recognizing the need to allow the controllers to adapt the displays to their own skill level?
3. Determining the optimal data structures for the retrieval of auxiliary information by the controllers.

The general endorsement of the interactive graphics concept by controllers during the evaluation trials indicates that these questions should be pursued.

5 CONCLUSIONS

Summary

An ergonomically sound, prototype ATC workstation incorporating the most recent advancements in computer graphics and interactive graphic interfaces was successfully implemented and evaluated, with favourable results, by operational air traffic controllers. The evaluation enabled the designers and controllers to answer many questions and, more importantly, to identify a large number of issues for further study.

The evaluation trials of the ATC workstation clearly indicated that operational controllers could move rapidly into an electronic environment provided that the displays capitalize on the processing power of the automated system. In the course of their limited exposure to the prototype during the simulations, the controllers readily adapted to the interactive graphic displays and menu-driven user interface and responded enthusiastically to the way menus were used to improve access to operational information.

Because it is difficult to improve on the ease with which data can be scribbled on paper flight strips, little performance improvement can be expected regarding the task of manually updating flight information without resorting to voice input technology. However, it is expected that the automation of certain controller activities (e.g. estimate calculation, estimate passing) will result in a reduced need for manual information updates and consequently an improvement in controller productivity in an electronic environment.

Conclusions

Radar position

Hand-off

Although there were some complaints about the number of steps required, many of the controllers were able to adapt quickly to using the mouse to perform hand-offs. The interaction method used to implement the hand-off function was compromised by the lack of a "recall" function which would have enabled controllers to recover from errors. There are a number of improvements which could easily be made to reduce the number of steps and reduce errors. These are discussed in the recommendations section.

Range information

While controllers are becoming familiar with new display devices, it is necessary to provide visual cues, such as range rings or a grid, which will aid in the estimation of range information.

Flight data position

Flight strip bays

Some of the controllers are not comfortable having access to only one flight strip bay at a time. When the viewing of flight strips is limited to one bay, it is more difficult for the controller to compare two strips located in different bays. This, in turn, makes it more difficult to follow the progress of a flight which passes over several fixpoints within the same sector. It appears that at least two bays of flight strips must be provided especially if the controllers are to be able to perform procedural control. The actual number of bays required will depend on the size and geography of the sector, the type of control and the number of mandatory reporting points.

Flight strip sequencing

The automatic sorting of flight strips can cause problems when the controller is updating the fix time. With the current prototype software, updating the fix time causes the system to re-sort the flight strip bay automatically. The unexpected re-ordering of the strips can be very disorienting and confusing to the novice user.

This problem can be resolved either by reverting back to a manual sorting system or by having the system request confirmation from the controller before performing the sorting.

Elevation display

Because of the mixed response received from the controllers regarding this feature, it was concluded that the elevation display is a slightly flawed tool which nevertheless has considerable potential in the display of flight progress information if certain improvements can be made. The graphic presentation of flight data allows the controller to obtain an overview of the impending air traffic situation very quickly.

It is suspected that controllers did not feel comfortable with the elevation display because of instances when there were discrepancies between the elevation display and the radar display. Although the discrepancies can be corrected by manually editing the flight data, this procedure can be time consuming.

In the current software version, the horizontal scale in the elevation display represents time rather than distance. This may have caused some confusion for controllers who are not accustomed to this type of display. However, it was not possible to determine which of type of scale (time or distance) is more appropriate for this task.

There are several relatively straight forward ways in which the elevation display can be improved. These are described in the Recommendations section of this report.

User interface

Input devices

Many of the controllers who took part in the evaluation were not satisfied with the optical mouse provided with the prototype workstation. There are several possible reasons for this dissatisfaction.

1. Unfamiliarity. Because of the historical use of joysticks and trackballs in air traffic control, controllers are more familiar with these devices than mice.
2. Mouse pad boundary. Controllers were confused when they ran the mouse off the edge of the mouse pad while trying to move the cursor across the screen. They need to be told that the mouse can simply be picked up and repositioned on the pad without affecting the cursor.
3. Orientation sensitivity. The type of optical technology used in the mouse provided with the prototype workstation requires that the user maintain proper *orientation* between the mouse and the pad. If the mouse deviates from the correct orientation by more than plus or minus 45 degrees, the cursor no longer behaves in a predictable manner.
4. Mouse pad sliding. When the bottom of the mouse becomes dirty, the friction between it and the mouse pad can become greater than the friction between the mouse pad and the table. This results in the pad having a tendency to slip on the table while the controller is trying to move the mouse across its surface.

Therefore, it was concluded that the optical mouse as used in this prototype is *not* a suitable device for air traffic control. A mechanical mouse with low friction is preferred to the optical mouse used in this prototype because there are no problems with mouse pad boundaries or slipping and no sensitivity to orientation. However, that is not to say that *all* optical mice are unsuitable for this application. An optical mouse would be suitable for air traffic control if it met the following criteria:

Development of an Ergonomically Sound Air Traffic Control Workstation

1. There can be no sensitivity to orientation between the mouse and the mouse pad.
2. If a special surface is required to operate the mouse, it must be possible to install a continuous sheet of this material into the worksurface of the console.

Graphic style

In considering the graphic design of the prototype displays, controllers prefer an understated graphic treatment, probably because it is less distracting to the task at hand. This is consistent with the experience of the contractor which has indicated that bold, high contrast, graphic treatments should be reserved for emergency situations.

Data editing

One of the innovative features of the ATC workstation was the ability to edit numeric flight progress information using only the mouse. In spite of the novelty of this feature and the unfamiliarity of the controllers with the mouse, many of them were able to adapt to this feature very quickly and use it in an effective manner. However, if the response of the display to the movement of the mouse is not immediate and continuous, this feature will be an annoyance to the user.

Conclusions

6 RECOMMENDATIONS

Summary

Because the prototype constructed during this project is the first step in an iterative process, it doesn't represent a final solution to the problem of the electronic presentation of flight progress information. As is apparent from the results of the evaluation, there are several issues which must be addressed before controllers will be completely satisfied with the proposed workstation concept. On the basis of designer observations, controller comments, and data collected during the evaluation period, a number of suggestions for improvements or further work have been formulated. In general, they involve the following:

1. Improving the efficiency and flexibility with which the user can enter or update flight progress information.
2. The automatic detection of potential conflict situations and alerting of the controller.
3. The development of new display formats for both operational and flight progress information to reduce the required amount of window manipulation (e.g. scrolling, paging) .
4. The provision of additional visual cues (e.g. cocked strip) to enhance the controller's ability to remember pending actions and verify actions taken.

It is anticipated that the development of new data formats will involve giving the user more control over the size, content and location of data display windows. It is recognized, however, that an *excessive* amount of flexibility could allow some individuals to create suboptimal display

Recommendations

formats. It will be necessary to perform further evaluation studies with the next iteration of the prototype to determine the optimal level of flexibility.

It should also be pointed out that the user interface of future ATC workstations will be influenced by a number of newly maturing technologies. These technologies will have to be examined and their impact on the user interface must be assessed within the context of the Flight Data Modernization Project. They include the use of 20 x 20 inch raster displays, voice I/O and artificial intelligence.

The suggestions for improvements have been organized into categories and are presented below.

General

Conflict alert indicator

Graphic methods for indicating conflicting flights and/or flight plans should be explored and implemented in both the radar and flight data positions.

Procedural control simulation

In the interests of expediency, the simulation of a procedural control environment was executed using a radar airspace and flight data. Because of the differences between radar and non-radar situations, the realism of the simulation was somewhat compromised by this oversimplification. There are a number of recommended changes which would result in a more realistic procedural controls simulation.

1. A procedural (non-radar) control situation generally involves a much larger airspace in comparison with radar controlled areas. For this reason, it is recommended that the running time of a procedural control simulation should be considerably longer than the 30 minutes provided in this project because a longer startup time is required to allow aircraft to fill the larger airspace.

2. Since the controller depends on pilot position reports to maintain control in a non-radar situation, procedural airspace generally contains a larger number of reporting points compared with radar controlled areas.

Processor status indicator

The next iteration of the prototype software should involve the design and implementation of a processor status indicator which would warn the controller of computer failure.

Wrong way altitude indicator

In North America, certain flight levels are reserved for eastbound and westbound flight. However, in certain situations, controllers will occasionally *knowingly* assign aircraft to a "wrong way" altitude in order to reduce the likelihood of conflict. The next iteration of the ATC workstation should include a feature which will detect and provide a visual indicator of "incorrectly" assigned altitudes to act as a reminder to the controller.

Radar position

Colour usage

In the prototype radar display, the "picked" aircraft was displayed in red in order to differentiate it from "unpicked" aircraft. This proved to be disturbing and distracting to the controllers since red has traditionally been used to indicate warning. It is recommended that a colour other than red should be used to indicate picked aircraft.

Cursor shape

The next iteration of the prototype software should permit the exploration of various cursor sizes and shapes. A centre-weighted, cross-hair style of cursor should be included in this exploration. A cursor which is a fixed

Recommendations

ratio of the radar range (to be used to estimate distances) should also be included.

Flight data window

A small movable window which allows the radar controller to view minimal flight progress information for at least 4 aircraft should be implemented in the radar display. The contents of the window should be determined by using the aircraft pick function. Picking an aircraft would cause its flight data to be added to the display. Unpicking an aircraft would cause deletion of its data from the display. If no aircraft are picked, the flight data window could be made to disappear.

Hand-off

Further development work should explore ways to reduce the number of steps required to perform a hand-off. If a single-button mouse is used, the number of steps required to perform a hand-off could be reduced by the implementation of a "time out" feature on the hand-off function. E.g., after the hand-off function is activated and used, if another hand-off doesn't take place within 10 seconds (or some other arbitrary time period), then the hand-off function is automatically deactivated. The incidence of unintentional hand-offs could be reduced by having the cursor change shape whenever the hand-off function is active.

If a multi-button input device is used in the next iteration, the use of a dedicated button to invoke the hand-off function should be investigated. A hand-off "recall" function should also be implemented in the next iteration.

Hotline panel

Back lit LCD displays should be used in the hotline panels to improve readability under varying lighting conditions.

OWS window size/shape

A uniform window size and shape should *not* be used for the various OWS windows. Rather, the windows should be variably sized according to the

amount of information to be displayed. The size of the window should be the minimum required to display the information.

The next iteration of the ATC workstation should also give the controller the ability to manually change the size and shape of the window to show only part of the information.

Pick function

The current version of the ATC software only allows one aircraft to be "picked" at a time. The next iteration should support the picking of at least four aircraft at one time.

User definable OIDS window

The next iteration of the ATC workstation might include a user definable OIDS window in which the controller can specify exactly what information will appear in the window. An appropriate user interface for this application would include functions which are very similar to the "copy, cut and paste" operations used in Apple Macintosh personal computers.

OIDS-1B Implementation

While the original OIDS provides controllers with a quick reference to accurate, timely operational data, the proposed OIDS-1B attempts to fill the same need yet also functions as an electronic reference manual. It is suggested that these two functions interfere with each other. The encyclopedic nature of OIDS-1B, with its hundreds of pages of data, interferes with the controllers' ability to rapidly access a few vital bits of information. It is felt that this situation can be resolved only by a thorough analysis of the controllers' information needs and a complete re-design of the system to meet these needs in an optimal fashion.

Range Information

Distance estimating aids such as range rings or a grid pattern should be provided in the radar display. This feature should be optional with an on/off switch which is easily accessible to the controller.

Recommendations

Radar maps

A number of map levels can be superimposed on top of the radar display at the option of the controller. It is recommended that a map showing the boundaries of restricted areas be included in one of these levels.

Flight data position

Elevation display

Although the elevation display provides a useful visual summary of all the flights posted under a given fix, discrepancies between this display and the radar display can be unsettling to the controller. Manually resolving these discrepancies can be annoying and time consuming. It is recommended that, when aircraft come within radar range, the radar information should automatically update the elevation display. Because of the qualitative differences between information based on radar and flight plans, it is necessary to provide visual cues which enable the controller to determine the information source for any given aircraft shown in the elevation display. I.e., aircraft whose position is determined from flight data should have a distinctly different appearance from aircraft whose position is determined from radar.

In the current prototype software, the horizontal scale in the elevation display represents time. However, further exploration is required to determine which of type of scale (time or distance) is more appropriate for the task.

Although the elevation display was originally intended to be used to display flight progress information, comments from controllers have indicated that perhaps it might be used more effectively as a supplementary display format for radar information.

Filter functions

Radar displays are equipped with a number of filtering mechanisms which allow the controller to remove irrelevant information from the display on a temporary or permanent basis. A similar capability should be implemented in the flight data display. It will be necessary to provide visual cues to ensure that the controller is made aware when filtering actions are taking place.

Flagging

Controllers currently displace flight strips to one side (the so-called "cocked" position) to indicate to themselves that further action is required. After the action is performed, the strip is returned to its original position. An electronic equivalent to this action should be developed in the next iteration. It is suggested that a colour change may be a more practical way of indicating a cocked strip since displacing a strip uses up more screen space.

Flight data fields

The prototype software supports the editing of only a few data fields provided in the flight data "strip". In the interests of expediency, the ability to edit was provided only for data fields which change frequently. In subsequent iterations, the controller should be able to edit all flight data fields.

Flight strip bays

The next iteration of the prototype software should investigate the implications of providing more than one flight strip bay.

Flight strip sequencing

The automatic re-sorting of flight strips which is performed when a fix point or fix time is updated can be very disorienting and confusing to the novice user. There is a tendency to lose track of the strip you were working on resulting in much anxiety. There are several levels at which this problem can be addressed:

Recommendations

1. Resort back to a manual sorting system.
2. Require the computer to obtain permission or confirmation from the controller prior to performing the sort.
3. Allow the computer to perform a sort only when specifically requested by the controllers.

Alternative formats

Alternative formats for flight data display should be explored. Emphasis should be on determining the appropriate amount of control wielded by the user. What should be the range of values allowed for user-adjustable display variables?

Optimization

Future development work should explore ways of making it easier to enter and edit flight information from both the radar and flight data display. Emphasis should be on reducing the number of steps required for the various operations.

User interface

Data editing

One of the innovative features of the ATC workstation is the ability to edit numeric flight progress information using only the mouse. (See Appendix E for a detailed description of the interaction.) Further work is required to determine the optimal level of gain between mouse movement and the change in the numeric value of the display.

Although the controllers were able to adapt to this feature very quickly and use it in an effective manner, if the response of the display to the movement of the mouse is not immediate and continuous, this feature can

be annoying to the user. Further work is required to determine the response time threshold at which the feature becomes annoying. Not all of the controllers were able to adapt to this feature. Therefore, the ability to edit flight progress information using a numeric keypad should also be provided as an optional alternative to using the mouse. This type of user interface could be most effective if one hand is used for numeric data entry while the other is used for cursor control.

With the current prototype software, if a controller is editing a data field in a flight data strip, then he or she must confirm that change before starting to edit another field. A more effective arrangement would allow the controller to edit as many fields as required within a given strip and then to issue a single blanket confirmation at the end of the editing session. It may also be desirable to allow the controller to edit more than one strip at a time. (See Simultaneous tasks, below.) These features should be explored in the next iteration of the prototype software.

20 x 20 Inch display devices

It has been determined that 20 x 20 inch raster devices will be used to display both radar and flight data in future ATC consoles rather than the 19-inch (diagonal) devices used in this project. A considerable amount of work will be required to adapt the software and displays to the new display format. Implementation of the prototype software on the larger displays will be complicated by differences in scale, proportion and resolution. It is also necessary to rework the ergonomics of the console since the table heights and monitor positions/orientations which were specified for the 19-inch monitors are not suitable for the larger screens. Structural requirements will also have to be reviewed in order to accommodate the much greater weight and lack of mobility of the larger displays.

Emergency data displays.

On rare occasions, the controller must have quick access to emergency data displays in order to make an informed response to an air emergency (an example of an emergency VIPS display is the Fuel Dumping Procedures). Naturally, access to these displays must be made as easy as possible. The following guidelines are suggested.

Recommendations

1. If the user interface requires more than one menu level, the EMERGENCY menu item should be visible at all levels.
2. No more than one menu selection should be required to display the emergency information regardless of the menu level.

Fonts

In the next iteration, new fonts should be developed and introduced to improve the controllers' ability to extract information from the data displays. Larger or bolder (thicker) fonts should be used to emphasize information which is more important than the surrounding information. Smaller or lighter (thinner) fonts should be used to de-emphasize less important information.

Since it is the *relative* sizes and weights of fonts which is used to interpret level of importance, any scheme which allows the user to adjust the size of the fonts to account for individual differences in visual acuity must scale *all* of the displayed fonts by roughly the same amount so that the size relationship between different types of text remains the same.

Graphic style

In the graphic design of displays for the ATC workstation, understated graphic treatment should be used. Bold graphic treatments should be used only if they can be functionally justified.

Input devices

The trackball and mechanical mouse should be considered as alternatives to the optical mouse as input devices for the ATC workstation. If a mouse (mechanical or optical) is used as an input device, then a sufficiently long training period must be allocated to allow the controller to become familiar and comfortable with the mouse prior to evaluation.

A mechanical mouse with low friction is preferred to the optical mouse used in this prototype because mechanical mice can be used without a mouse pad. Therefore, the problems associated with the mouse pad (see section 5, Conclusions) would be avoided.

Development of an Ergonomically Sound Air Traffic Control Workstation

However, that is not to say that *all* optical mice are unsuitable for this application. An optical mouse would be suitable for air traffic control if the following criteria could be met:

1. There can be no sensitivity to orientation between the mouse and the mouse pad.
2. If a special surface is required to operate the mouse, a continuous sheet of this material must be built into and cover the entire worksurface of the console. In addition, this material must be resistant to scratching, soiling and other damage which could result from normal use in the ATC environment.

The use of voice input technology as a supplement or substitute for the mouse or trackball should be explored in future iterations of the prototype workstation

Multiple mouse buttons

Often, when a mouse (or trackball) with more than one button is being used, the use of the second or third buttons is only relevant in certain situations. If this is the case, then in those situations where the use of the other buttons is *irrelevant*, all of the mouse buttons should have the same effect.

Simultaneous tasks

The current version of the prototype software requires the controller to confirm changes to flight data before continuing to other tasks. This restriction makes it impossible for the controller to suspend a flight data editing session to attend to a more urgent task. (The editing session must be completed or aborted before a new task can be started.) The next iteration of the prototype software should explore the potential of modifying the confirmation requirement so that it is possible to initiate other tasks while in the midst of a flight data editing session. One possible benefit of this feature would be the ability to edit more than one flight data strip at a time.

Recommendations

Telephone handset location

The position of the telephone handset in the console was initially determined under the assumption that a discrete radio control panel and dual keyboards would be required. During the development process, the radio panel and one of the keyboards was eliminated. However, the position of the telephone handset was not revised to take advantage of this. It is recommended that the telephone panel be moved closer to the centre of the console in the next iteration.

Software limitations

There were a number of known limitations in the prototype software which the contractor was unable to resolve prior to the evaluation period. The presence of these limitations in the software does not imply that the ATC issues related to these problems were considered unimportant. These limitations, which are described below, should be addressed in the next iteration of the ATC workstation.

Radio controls/displays

Although the radar controller makes frequent use of the radio, it generally involves only the use of a transmit function which can be activated with a foot switch or hand held switch. Because the other radio controls and displays (e.g. volume control, output mode) are accessed at a relatively low frequency, these were not fully implemented in the prototype. The interactive graphic radio panel implemented in the prototype software is only an appearance prototype, i.e. it is intended to convey the appearance and the interactive behaviour of the radio control/display panel. Although simulated radio communication was provided in the prototype workstation, volume and output mode could not be controlled directly using the interactive graphic radio panel.

Removal of flight strips

The current version of the prototype software does not support the removal of flight "strips" from the flight data display after the corresponding flight has been handed-off to an adjacent controller.

Route revision

The prototype software contained a "bug" which occasionally made it impossible to make changes to the aircraft routing in the flight progress information. If the controller took more than ten seconds to specify a change, then the change would be ignored.

Squawk Ident

The next iteration of the prototype software should support the simulation of the "squawk ident" function.

Recommendations

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Appendix A:

Traffic Volume and Communications Activity for Simulation Exercises

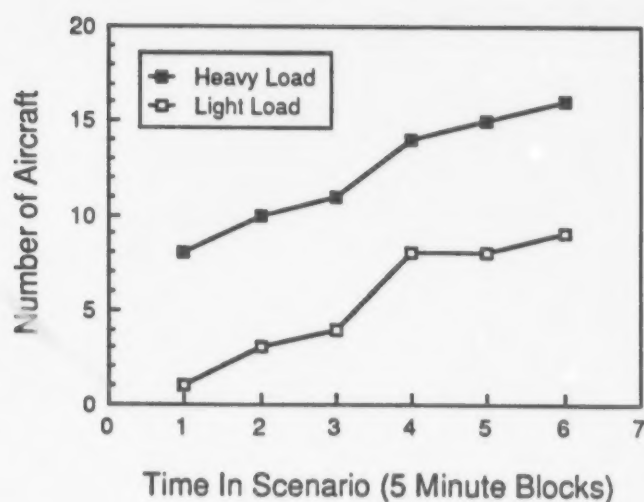


Figure A-1: Light and heavy traffic loads for the Centralia Sector.

Appendix A

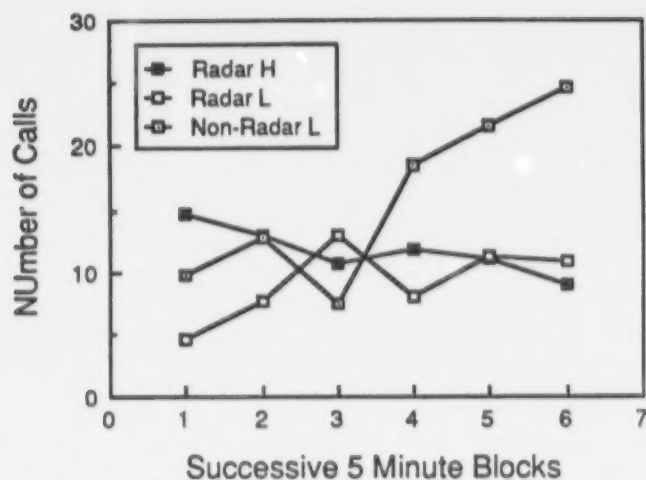


Figure A-2: Air-ground communications generated in the heavy (H) and light (L) radar and non-radar scenarios.

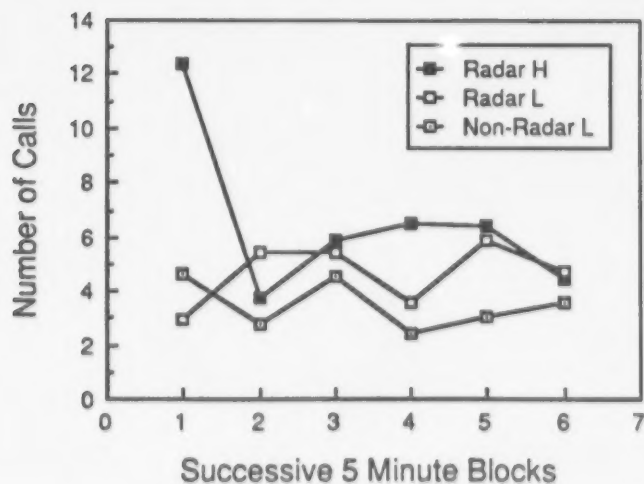


Figure A-3: Ground communications (i.e., combined hotline and PAX calls) for heavy (H) and light (L) radar and non-radar scenarios.

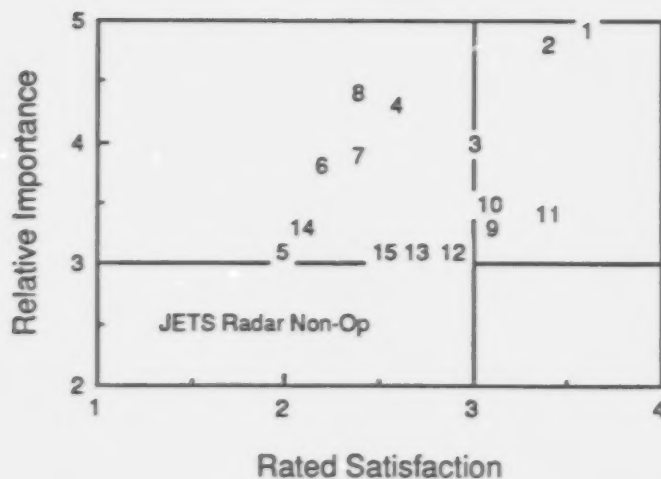
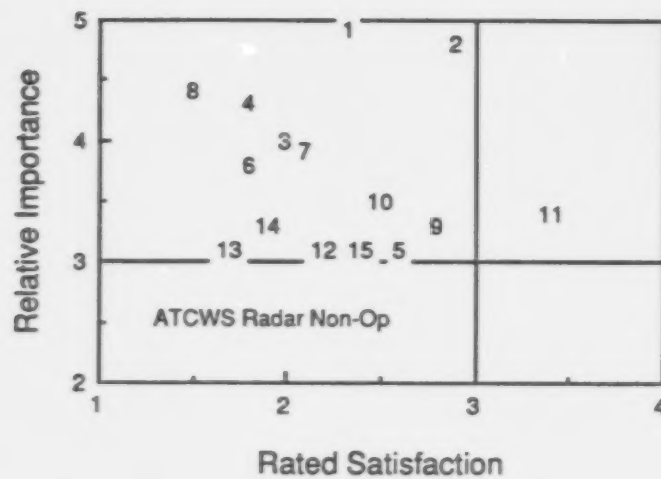
APPENDIX B: **Data for Non-operational Controllers and Engineers**

Non-operational controllers and engineers within ATS participated in informal simulation exercises in order to acquire first hand experience with the prototype ATCWS. Questionnaire data were obtained for 18 non-operational subjects and are presented in Figures 1 and 2. Some of the non-operational subjects reported that they had only limited experience with the JETS equipment but all of those who responded to the questions had direct or indirect knowledge of the JETS displays and the standard flight data board.

The data presented in both figures reflect an *overall negative bias* toward *both* workstations. The general negative bias in the non-operational ratings can be observed, in particular, through a direct comparison between Figure 1 of this *Appendix* and the results reported for the *operational* controllers (refer to Figure 3). The data also suggested that the non-operational subjects were making fewer *differential ratings across components and between workstations* for a given position (i.e., radar or data). This observation would be consistent with the fact that as a group they reported that they were less familiar with JETS and therefore would be less able to make the same discriminations as the operational controllers.

Similarities were noted, however, between the two groups of subjects. For example, the problem of maintaining an awareness of revisions in flight data at the ATCWS radar position was noted by both groups and the difficulty inherent in reviewing the flight data for future conflicts was again reflected in the ratings assigned to the data position.

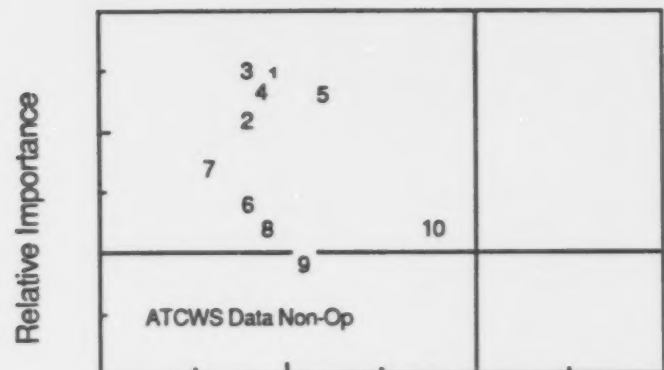
Appendix B



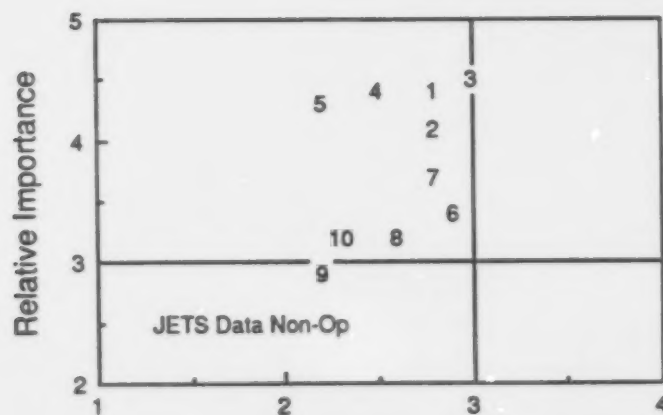
- | | | |
|---------------------------|----------------------------------|-----------------------------|
| 1. Checking separation | 6. Access to flight progress | 11. IM display refresh rate |
| 2. Resolving conflicts | 7. Revision of flight data | 12. Housekeeping activities |
| 3. Processing deviations | 8. Awareness of revisions | 13. Status information |
| 4. Reviewing flight data | 9. Ability to select IM features | 14. OIDS display |
| 5. Access to flight plans | 10. Ease of feature selection | 15. Ease of OIDS selection |

Figure B-1. Ratings obtained for non-operational controllers and staff for the radar position in the ATCWS (upper plot) and in JETS (lower plot).

Development of an Ergonomically Sound Air Traffic Control Workstation



Rated Satisfaction



Rated Satisfaction

- | | | |
|---------------------------|-----------------------------|-----------------------|
| 1. Processing time info | 5. Updating flight progress | 9. Status information |
| 2. Flight plan amendments | 6. History of changes | 10. VIPS displays |
| 3. Reviewing flight data | 7. Access to board | |
| 4. Conflict processing | 8. Housekeeping activities | |

Figure B-2. Ratings obtained for non-operational controllers and staff for the data position in the ATCWS (upper plot) and in JETS (lower plot).

Appendix B

APPENDIX C:
Evaluation briefing notes and questionnaire

EVALUATION OF PROTOTYPE ATC WORKSTATION (ATCWS)

Background

The prototype ATCWS was developed in order to explore alternative display graphics and the controller interface that would be suitable in the next generation of controller workstations. The prototype with which you will be working represents the first iteration of several concepts that may be explored and it is not to be considered as a finished model or configuration. Development work will be continuing and various graphic displays will be studied before any recommendations are made.

Evaluation

The intent of the evaluation trials is to have the interests and experience of a range of ATC personnel represented in the initial critique of the prototype ATCWS. The simulations are based on the Centralia sector of Toronto ACC. Most controllers will not have had prior experience with this sector but the focus of the evaluations is on the controller's interaction with the displays and equipment. It is not the intention to look at controller performance but rather to provide an appropriate environment in which comments and constructive criticism are encouraged. Your participation in the evaluation will involve completing two questionnaires before the simulations and one afterward. In the first questionnaire you will be asked to assess the importance of various tasks and components in controlling traffic. The other two questionnaires ask you to assess how well the JETS or the prototype equipment enables one to perform the various tasks. There will be an opportunity for discussion after the simulations and the questionnaires are completed.

General Procedure

The schedule for the evaluation is shown on the following page. Between simulations and when you are not actually controlling traffic, you are asked to adjourn to an adjacent area. The same procedure will be followed if technical problems develop during the simulation.

Your participation in the evaluation trials is appreciated and your comments will be most useful in the continuing development of a new controller workstation. Please review the simulation schedule and then proceed to the questionnaires that follow.

Pre-Exercise Importance Questionnaire

(Confidential When Completed)

Please provide the following information:

Date _____

Name _____

Age _____ Height _____

Length of Experience/
as a Controller _____

Current Title/
Position _____

Location/
Centre _____

If a current controller, what is your
specialty? _____

1. Without specific reference to either the existing consoles for JETS or the prototype Common Controller Workstation, indicate how important the following components and functions are for you as a controller. Rate each component or function on a scale from 1 to 5 where 5 is assigned to those that are "extremely important". Circle the appropriate value.

Not At All Important	Slightly	Moderately	Very	Extremely Important
1	2	3	4	5
_____	_____	_____	_____	_____

Enroute Radar Position

Checking and evaluating separation	1	2	3	4	5
Resolving conflicts	1	2	3	4	5
Processing course deviations	1	2	3	4	5
Reviewing flight data for present/ future separation	1	2	3	4	5
Access to flight plans	1	2	3	4	5
Access to flight progress data	1	2	3	4	5
Revision of flight data	1	2	3	4	5
Awareness of revisions to flight data	1	2	3	4	5
Ability to select IM features (filters etc.)	1	2	3	4	5
Ease of feature selection	1	2	3	4	5
IM display refresh rate	1	2	3	4	5
Housekeeping activities	1	2	3	4	5
Information on status of control equipment	1	2	3	4	5
OWDS display	1	2	3	4	5
Ease of OWDS page selection	1	2	3	4	5

Enroute Data Position

Processing departure/enroute time information	1	2	3	4	5
Processing flight plan amendments	1	2	3	4	5
Reviewing flight data for present/future separation	1	2	3	4	5
Performing conflict processing	1	2	3	4	5
Ease of updating flight progress information	1	2	3	4	5
Retaining history of changes	1	2	3	4	5
Simlutaneous access to any part (any fix) of flight progress board	1	2	3	4	5
Housekeeping activities	1	2	3	4	5
Access to system status information	1	2	3	4	5
OIDS display	1	2	3	4	5
Ease of OIDS page selection	1	2	3	4	5

General

Efficiency of [JETS] cursor movement	1	2	3	4	5
Rapid access to hotline/telephone controls	1	2	3	4	5
Seating provision	1	2	3	4	5

Comments

Pre-Exercise JETS Questionnaire

(Confidential When Completed)

1. With specific reference to the **existing** JETS consoles, indicate how satisfied you are in terms of the following components and functions. Rate how satisfied you are with each component or function on a scale from 1 to 5 where 5 indicates that you are "extremely satisfied". Circle the appropriate value.

Not At All Satisfied	Slightly	Moderately	Very	Extremely Satisfied
1	2	3	4	5
_____	_____	_____	_____	_____

Enroute Radar Position

Checking and evaluating separation	1	2	3	4	5
Resolving conflicts	1	2	3	4	5
Processing course deviations	1	2	3	4	5
Reviewing flight data for present/ future separation	1	2	3	4	5
Access to flight plans	1	2	3	4	5
Access to flight progress data	1	2	3	4	5
Revision of flight data	1	2	3	4	5
Awareness of revisions to flight data	1	2	3	4	5
Ability to select IM features (filters etc.)	1	2	3	4	5
Ease of feature selection	1	2	3	4	5
IM display refresh rate	1	2	3	4	5
Housekeeping activities	1	2	3	4	5
Information on status of control equipment	1	2	3	4	5
OIDS display	1	2	3	4	5
Ease of OIDS page selection	1	2	3	4	5

Enroute Data Position

Processing departure/enroute time information	1	2	3	4	5
Processing flight plan amendments	1	2	3	4	5
Reviewing flight data for present/future separation	1	2	3	4	5
Performing conflict processing	1	2	3	4	5
Ease of updating flight progress information	1	2	3	4	5
Retaining history of changes	1	2	3	4	5
Simlutaneous access to any part (any fix) of flight progress board	1	2	3	4	5
Housekeeping activities	1	2	3	4	5
Access to system status information	1	2	3	4	5
OIDS display	1	2	3	4	5
Ease of OIDS page selection	1	2	3	4	5

General

Efficiency of [JETS] cursor movement	1	2	3	4	5
Rapid access to hotline/telephone controls	1	2	3	4	5
Seating provision	1	2	3	4	5

Comments

Post-Exercise Evaluation Questionnaire

Air Traffic Control Workstation

(Confidential When Completed)

Name _____

1. With specific reference to the **prototype** Air Traffic Control Workstation, indicate how satisfied you are in terms of the following components and functions. Rate how satisfied you are with each component or function on a scale from 1 to 5 where 5 indicates that you are "extremely satisfied". Circle the appropriate value.

Not At All Satisfied	Slightly	Moderately	Very	Extremely Satisfied
1	2	3	4	5
_____	_____	_____	_____	_____

Enroute Radar Position

Checking and evaluating separation	1	2	3	4	5
Resolving conflicts	1	2	3	4	5
Processing course deviations	1	2	3	4	5
Reviewing flight data for present/ future separation	1	2	3	4	5
Flight data display for selected aircraft	1	2	3	4	5
Access to flight plans for selected aircraft	1	2	3	4	5
Access to flight progress data	1	2	3	4	5
Revision of flight data	1	2	3	4	5
Awareness of revisions to flight data	1	2	3	4	5
Potential to select IM features	1	2	3	4	5
Ease of feature selection	1	2	3	4	5
IM display refresh rate	1	2	3	4	5
Housekeeping activities	1	2	3	4	5
Information on status of control equipment	1	2	3	4	5
OWDS display	1	2	3	4	5

Enroute Radar Position (Cont'd)

Ease of OIDS page selection	1	2	3	4	5
Ease of learning the operations	1	2	3	4	5
Ease of using the workstation	1	2	3	4	5
Correction of errors	1	2	3	4	5
Logic of procedures or actions	1	2	3	4	5

Enroute Data Position

Processing departure/enroute time information	1	2	3	4	5
Processing flight plan amendments	1	2	3	4	5
Reviewing flight data for present/future separation	1	2	3	4	5
Performing conflict processing	1	2	3	4	5
Ease of updating flight progress information	1	2	3	4	5
Retaining history of changes	1	2	3	4	5
Access to alternative fix postings	1	2	3	4	5
Housekeeping activities	1	2	3	4	5
Access to system status information	1	2	3	4	5
VIPS (Airways and Approach) displays	1	2	3	4	5
Ease of learning the operations	1	2	3	4	5
Ease of using the workstation	1	2	3	4	5
Correction of errors	1	2	3	4	5
Logic of procedures or actions	1	2	3	4	5

General

Efficiency of the cursor movement	1	2	3	4	5
Access to hotline/telephone controls	1	2	3	4	5
Seating provision	1	2	3	4	5

2. Performance at the Workstation

2.1 Enroute Radar Position

- a) Think of an instance when you were at the **Radar** position and you felt that you were being particularly **effective**. What were you doing at the time and what features of the workstation were you using?

- b) Think of an instance when you were at the **Radar** position and you felt that you were being particularly **ineffective**. What were you doing at the time and what features of the workstation were you using?

- c) What modifications would you like to see at the **Radar** position?

2.2 Enroute Data Position

- a) Think of an instance when you were at the **Data** position and you felt that you were being particularly **effective**. What were you doing at the time and what features of the workstation were you using?

- b) Think of an instance when you were at the **Data** position and you felt that you were being particularly **ineffective**. What were you doing at the time and what features of the workstation were you using?

- c) What modifications would you like to see at the **Data** position?

2.3 Single Controller

- a) Think of an instance when you were working the sector by **yourself** and you felt that you were being particularly **effective**. What were you doing at the time and what features of the workstation were you using?

Radar:

Non-Radar:

- b) Think of an instance when you were working the sector by **yourself** and you felt that you were being particularly **ineffective**. What were you doing at the time and what features of the workstation were you using?

Radar:

Non-Radar:

- c) What modifications would you like to see in the workstation in order for it to be more effective in a **single-controller configuration**?

Radar:

Non-Radar:

Comments

3. Please add any other comments or observations that would contribute to the further development of the workstation.

**Thank you for completing this questionnaire.
Your contribution is appreciated.**

APPENDIX D:

Controller Comments from Evaluation

Introduction

After completing the simulation sessions, the controllers were asked to provide written comments in response to a questionnaire. (The questionnaire is shown in Appendix C.) Because of their lack of structure these comments cannot be subjected to rigorous scientific analysis. Nevertheless, a discussion of the comments is included in this section because it is felt that it provides insight into possible improvements to consider for future iterations.

Radar Position

Hand-off

Although 5 of the 12 subjects felt that they were being particularly effective while they were using the "hand off" feature of the ATC workstation, one controller commented that the hand-off feature was "terrible" and another described it as "cumbersome".

Currently, the hand-off function is operated in the following manner: The function is turned "on" by selecting the "hand-off" menu item with the cursor, the aircraft to be handed off is selected, and then the function is deactivated by selecting the hand-off menu item again. This interaction method was devised to make it easier to perform multiple handoffs. However it is obvious that this procedure makes *single* handoffs more difficult. In addition, it increases the likelihood of an accidental hand-off which can occur if the controller forgets to deactivate the hand-off function.

Appendix D

During the simulation sessions, the accidental hand-off problem was further aggravated by the omission of a "recall" function in the prototype software.

Flight data access from radar position

Four of the controllers felt that they were being particularly ineffective while trying to access flight data. Some of this may be attributed to the fact that only one strip bay is provided in the flight data display and that the bay does not have sufficient capacity. These issues are discussed in greater detail below.

During the development of the flight data display, it was assumed that it wasn't necessary to have all the data visible all the time because the data could be rapidly called up on demand. However, it neglected the fact that the radar controller must often refer to the flight data. When working with JETS, all of the data is visible as strips. However, when two controllers are working with the ATC workstation, if the radar man wishes to look at flight data which is not currently visible, he or she must ask the data man to display it or use the data position mouse. Possible solutions include using a third screen to provide flight data for the radar position or allowing the radar man's cursor to cross over into the flight data display and manipulate menus.

Two of the 12 controllers felt that they were ineffective while editing flight data. One felt that editing the flight route "took far too many actions and time". This implies that the flight data editing should be made even easier than it is in the prototype.

Estimating distance

Seven of the 12 controllers expressed dissatisfaction with their ability to estimate distances on the situation display in the radar position, e.g. distance between aircraft, distance from aircraft to fixes or sector boundaries. This dissatisfaction resulted from a combination of factors: unfamiliarity with the 19" display device, unfamiliarity with the sector being used for the simulation and the lack of visual cues such as a cursor which is a fixed ratio of the radar range (as in JETS). Most of these controllers suggested the use of range rings or a grid.

Selective OIDS

Four of the controllers commented that they would like to be able to specify a window which would contain a very small and specific subset of the information which would normally be displayed as a part of OIDS.

Apparently, the controllers would like to have a very compact, permanently displayed window which contains information which is referred to on a very frequent basis. The nature of this information would naturally depend on the specific needs of each controller. A small permanently displayed window would reduce the number of actions required to view operational information and would also reduce the obstruction of the radar display by the OIDS window. Because of its size, the OIDS display as implemented in the prototype cannot be displayed constantly because it occupies too large a percentage of the radar display. For example, low altitude sectors require frequent reference to altimeter readings in several different locations.

One of the controllers suggested that OIDS screens might be activated from the radar display but displayed on the flight data display.

Flight Data Position

General

Five of the 12 controllers felt that they were not particularly effective while working at the flight data position of the prototype. Although much of this feeling is related to the limited functionality of the prototype software, other contributing factors include:

- (1) lack of familiarity with the airspace/airway structure (only one pair of controllers had actually controlled in the Centralia sector before).
- (2) lack of time to become completely familiar with the functionality of the prototype.
- (3) change in the format of flight progress information display

Appendix D

- (4) lack of familiarity with the optical mouse and direct manipulation interfaces

Some specific issues which the controllers criticized are described in detail below.

Elevation Display

Two of the controllers made favourable comments regarding the elevation view window in the flight data position, one referring to it as "the very best tool I've seen in this workstation". Some suggestions were also made for improving it. The fix identifier should be displayed somewhere near the vertical line which represents the fix. When aircraft come within radar range, the radar information should automatically be used to update the elevation display. It will be necessary to indicate graphically whether an aircraft position on the display is based on the flight plan or radar information.

Flight strip bays

Only one flight strip bay was provided in the prototype. Two of the controllers commented that at least a second bay was required. The implementation of a second bay would reduce the amount of time spent switching the flight strip bay from one fixpoint to another.

Flight strip marking

In general, the controllers indicated that they would like see an increase in the number of data fields which can be viewed and edited. Specifically they mentioned the following fields: controller estimate, revised controller estimate, pilot estimate, revised pilot estimate, hold instructions and requested reports. The ability to input and delete symbolic data such as tick marks, asterisks, and strokes is also considered important. One controller suggested retaining the bold markings currently used to distinguish between arrivals (+), departures (/) and overflights (|ALT|).

Route display

Three of the controllers complained about the presentation of route information. One of the controllers did not like having to scroll the route information.

Simultaneous tasks

Air traffic controllers depend on and take great pride in their ability to perform several tasks at the same time. Many of the complaints regarding the input of flight data were related to occasions when the controller was in the middle of a task which was preempted by another task of higher priority. When using paper strips, it is very easy for the controller to suspend the performance of one task, attend to another task momentarily, and then resume the original task. However, this type of interaction is not supported by the current prototype software. Only one task can be performed at a time and each task must be completed before a subsequent task can be started.

User Interface

Input devices

Five of the 12 controllers were not happy with the optical mouse provided with the prototype workstation. Of those, three said that they would prefer to use a trackball. One said that he would be willing to use a *mechanical* mouse. There are several possible reasons for this dissatisfaction with the optical mouse.

The mouse has been proven to be extremely compatible device for cursor positioning tasks, (Card et al). Moreover, experienced users typically prefer the optical mouse over the mechanical mouse because of its lower friction and mechanical inertia. However, Card reports that "inexperienced users are often bewildered about what to do when they run the mouse into the side of the keyboard trying to move the cursor across the screen". The

controllers faced similar bewilderment when they ran the mouse off the edge of the reflective pad required to operate the optical mouse. They need to be told that the mouse can simply be picked up and repositioned on the pad without affecting the cursor.

The optical mouse introduces an additional confusion to the controllers. In addition to imposing the relatively confining boundary of mouse pad, the use of optical technology also requires that the user maintain proper *orientation* between the mouse and the pad. If the mouse deviates from the correct orientation by more than plus or minus 45 degrees in either direction, the cursor no longer behaves in a predictable manner. For a typical computer user, mouse orientation is seldom a problem because the mouse is used to either side of a keyboard and is naturally held in the correct orientation. However, because there is no discrete keyboard on the table surface of the workstation, there is a tendency for controllers to use the mouse in the area directly in front of them. It is also very easy for a controller to hold the mouse incorrectly when attempting to operate both workstation positions alone.

Another problem resulting from the use of the pad: When the bottom of the mouse becomes dirty, the amount of friction between it and the pad can become greater than the friction between the pad and the table. This results in the pad having a tendency to slide around on the table while the controller is trying to move the mouse across its surface.

Data editing

One of the innovative features of the ATC workstation was the ability to edit numeric flight progress information using only the mouse. The intent behind this innovation was to minimize the amount of keyboard activity required by the controller. Four of the 12 controllers felt that they were being particularly effective while they were using this feature (although one complained that he was occasionally annoyed by a loss of smoothness in the updating of the numeric display).

Development of an Ergonomically Sound Air Traffic Control Workstation

Fonts

One of the controllers suggested that the size and the "brightness" of the fonts should be adjustable by the user at both the radar and flight data positions.

Appendix D

APPENDIX E:
Interaction Description Diagrams

FLIGHT DATA EDITING: FIX TIME

1. Point at fixtime field in flight data window.

☐ FLIGHT DATA		21:05
390 2117 	UA881 B727/A 478 3413	BTV / / BUF J547

2. Press and release L mouse button.

*Display present time under
fixtime field.
Highlight both time fields.
Display option boxes.*

☐ FLIGHT DATA		21:05	
OK Abort	390 2117 2105 	UA881 B727/A 478 3413	BTV / / BUF J547

3. Press and hold L mouse button.
Move cursor up or down.

*As cursor is moved up, value of
time field increases. If cursor is
moved down, value decreases.*

☐ FLIGHT DATA		21:05	
OK Abort	390 2117 2126 	UA881 B727/A 478 3413	BTV / / BUF J547

Continued next page.

FLIGHT DATA EDITING: FIX TIME (continued)

4. Release L mouse button.
Point at OK button.

		☐ FLIGHT DATA	21:05
OK		UA881 B727/A	BTV //
Abort	2117 2126	478 3413	BUF J547

5. Press L mouse button.

Highlight OK button.

		☐ FLIGHT DATA	21:05
OK		UA881 B727/A	BTV //
Abort	2117 2126	478 3413	BUF J547

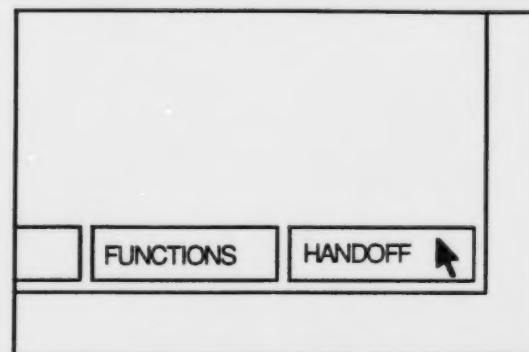
6. Release L mouse button.

*Remove confirmation boxes.
Remove highlight from fixtime
fields.*

		☐ FLIGHT DATA	21:05
		UA881 B727/A	BTV //
	2117 2126	478 3413	BUF J547

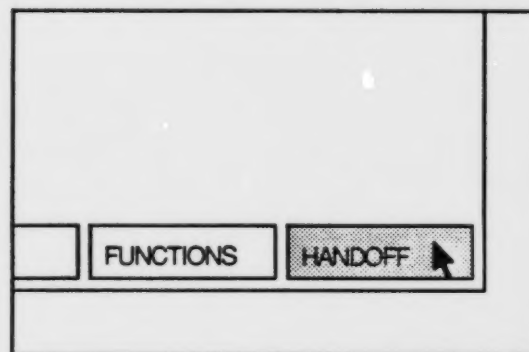
HAND-OFF ACCEPTANCE

1. Point at "HANDOFF" menu button.

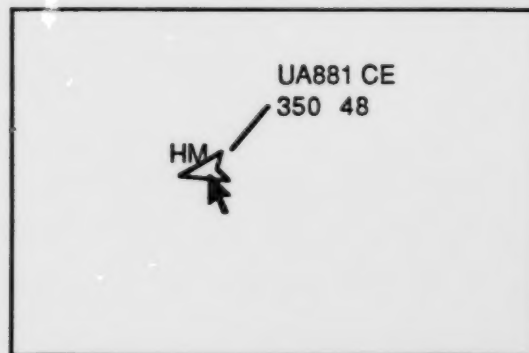


2. Press and release L mouse button.

Highlight HANDOFF button.



3. Point at flashing aircraft icon.

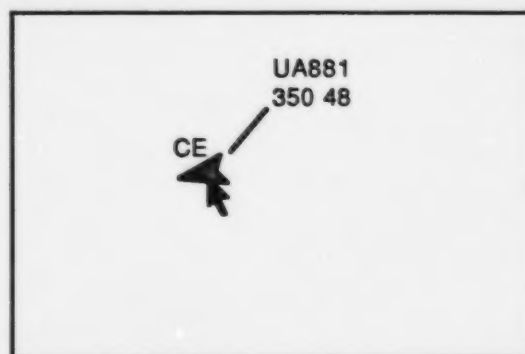


Continued next page.

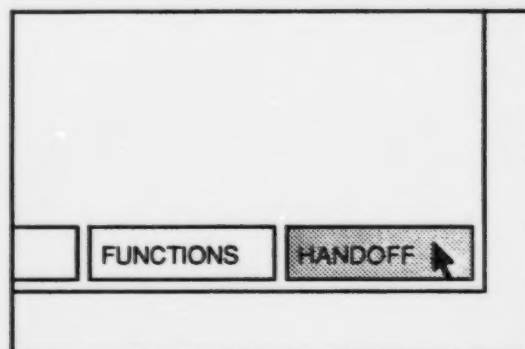
HAND-OFF ACCEPTANCE (continued)

4. Press and release L mouse button.

*Highlight aircraft icon.
Remove pending CJS.
Change current CJS to "CE".*

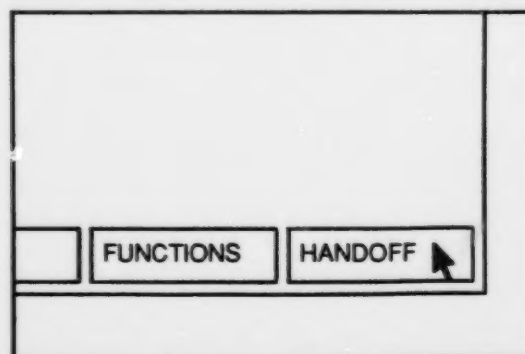


5. Point at HAND-OFF menu item.



6. Press and release L mouse button.

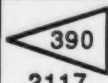
*Remove highlight from
HAND-OFF button.*



ROUTE INFORMATION: SCROLLING

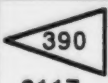
1. Point at route field in flight data window.

Press and hold L mouse button.

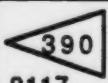
☐ FLIGHT DATA		21:05
 2117	UA881 B727/A 478 3413	BTV // BUF J547

2. Move cursor up or down.

Route information tracks cursor movement.

☐ FLIGHT DATA		21:05
 2117 2105	UA881 B727/A 478 3413	BUF J547 PMM V84

3. Release L mouse button.

☐ FLIGHT DATA		21:05
 2117 2126	UA881 B727/A 478 3413	J547 PMM V84 PAPPI

HOTLINE VOLUME CONTROL

A: Normal Display

CLE 58	CE	HM	DPTR
---------------	-----------	-----------	-------------

B. When either of the volume control buttons under the "CLE 58" channel are pressed, the volume indicator is displayed. Each subsequent press of the volume adjust button causes the volume indicator (and volume itself) to increase or decrease by one unit.

	CE	HM	DPTR
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C. If the volume adjust button is held for more than one second, the volume indicator (and the volume) increases or decreases at a rate of 1 bar every 0.25 seconds.

	CE	HM	DPTR
---	-----------	-----------	-------------

D. When the volume button is released, the volume indicator continues to be displayed for 2 seconds and then the display reverts back to the normal display.

CLE 58	CE	HM	DPTR
---------------	-----------	-----------	-------------

Appendix E

APPENDIX F:

Plates

- A: Radar display.
- B: Flight data display.
- C: Computer generated image of console.





